Proceedings of Two Day Workshop on Enhanced and Synthetic Vision for Transport Aircraft

25-26 April 2008
SP 0811

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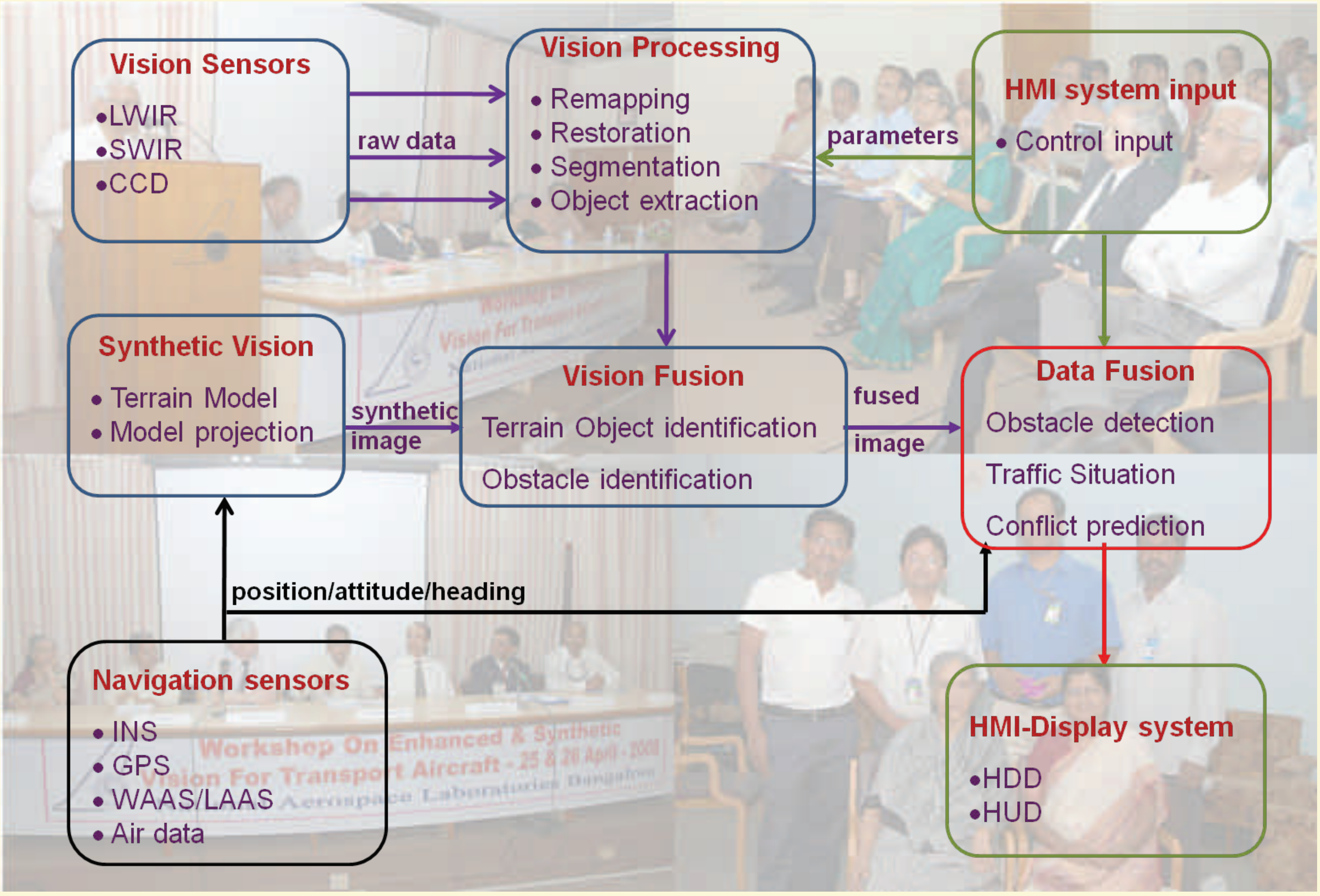

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Summary

The regional transport aircraft (RTA-70) proposed to be developed at NAL is expected to have the capability of reliable and safe operation from airports with minimal infrastructure and instrumentation facility under all-weather conditions. Enhanced and Synthetic Vision (ESV) technology aided by satellite navigation has the potential to meet this requirement. A two day workshop on 'Enhanced and Synthetic Vision for Transport Aircraft' was organized by the Multi Sensor Data Fusion group, Flight Mechanics and Control Division with the objective of examining the state of art and identifying gaps in technology/knowledge base in this area and chalk out a plan of action for ESV development at NAL..

The inaugural session included addresses by Dr. A R Upadhya, Director, NAL, Dr. Kota Harinarayana, Raja Ramanna Fellow, NAL and Dr. S.V. Kibe, Programme Director, SATNAV, ISRO. The Two day workshop had fourteen invited lectures delivered by scientists and technologists from India and abroad who shared their work experience in related technology areas and thoughts on its use for ESV development. There were six thematic sessions. In the first session, Dr. Jharna Majumdar, Professor, East Point College of Engineering, Bangalore with her vast experience in development of "Image exploitation system for unmanned aerial vehicle", brought out the research areas in image processing that need to be addressed for ESV and some aspects of video geo registration. Prof. B.N. Chatterji, IIT Kharagpur covered issues related to content based image retreival. In the second session on "Visual Cues for pilots/Human Machine Interface Sqn Ldr. J. Sreeram, ASTE, Bangalore gave an insight into the flight test perspective on display concepts for synthetic vision followed by Cdr. Renganathan, Coral Technologies, Bangalore who gave an overview of computer graphics for modern cockpits and cockpit procedure trainers. This was followed by presentation of the activities at FMCD in the areas of synthetic vision and image fusion.

On 26th April, Dr. Ronald Kruk, Chief Scientist, CAE, Canada in his very lucid and informative presentation brought out the role of laboratory, simulator and flight test components in ESV development, as part of the third session. Dr. Dinesh Ramegowda, Honeywell Technology Solutions, Bangalore covered the multi spectral enhanced vision system development at Honeywell. The fourth session included two lectures on issues and solutions for image fusion by Dr. S.C. Jain, DEAL Dehradun and Dr. Subrata Rakshit, CAIR, Bangalore. In the fifth session on "Sensor Technologies", Dr. S.S. Negi, IRDE, Dehradun detailed the latest developments in infrared sensor technology while Dr. Nilesh M. Desai of ISAC, ISRO, Ahmedabad covered the microwave remote sensing and synthetic aperture radar. Dr. PP Mohanlal, VSSC, Trivandrum discussed the GPS aided INS for space capsule recovery experiments and launch vehicle systems. The workshop concluded with a 90 minute brain storming panel discussion by the panel members consisting of eminent scientists and transport aircraft pilots. Issues related to system requirement, sensors, pilot interface and system certification were discussed. The workshop provided a platform for the experts from various organizations to come together to arrive at a road-map for ESV development for RTA.

This Special Publication gives the abstracts of the presentations at the workshop including the presentation material. It also includes the Summary of the panel discussions which highlights future directions and research needs.

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Foreword by the Director

The regional transport aircraft proposed to be developed at NAL is expected to have the capability of operation from airports with minimal infrastructure and instrumentation facility under all-weather conditions in addition to providing high volume operation (HVO) in non-radar airspace and non-towered airports. One of the technologies that hold promise for achieving this is the “Enhanced and Synthetic Vision (ESV)” which provides the pilot the ability to see in all directions, even in reduced visibility conditions.

ESV is a combination of “Sensor Vision” and “Synthetic Vision”. The former presents the fused data of several imaging sensors and the latter generates a rendered image of an *a priori* database in any direction that the pilot chooses to look. To generate a better situation awareness, HUD symbology, including attitude, airspeed and altitude information is added over the underlying scene in the ESV.

FMCD, NAL has built up some expertise in areas of Synthetic Vision and muti-sensor data fusion over the last decade**.** In order to augment the capability for development of the ESV technology, this workshop is organized to bring together experts from national / international R&D organizations, academia, and industries to present their achievements and explore the possibility of deriving synergies.

I am happy to note that there are several lectures in the workshop by subject matter experts which will greatly benefit the scientific group planning to initiate work in this area. I am also glad that the Organizing Committee of the workshop is coming out with the book of abstracts which will be augmented by actual presentations and discussions.

I wish the workshop all success.

(Dr. A R Upadhya)

Director, NAL

Inaugural Address

Dr. Kota Harinarayana, Dr. Raja Ramanna Fellow, NAL

Communication facility is vital for economic development of any region. Air Connectivity if properly implemented would be able to accelerate economic development of interior regions of the country. The need is for air connectivity which is reliable and dependable and which does not depend on costly ground infrastructure. We need cost effective, on board systems that enable operation of regional aircraft in all weather conditions and independent of ground instrumentation facility. Synthetic vision and Enhanced vision equipment along with satellite navigation systems do have the potential to meet the requirement. The challenge is to develop low cost solutions with required safety and reliability. The workshop aims to examine the state of art, identify the gaps in the knowledge base and technology base and chalk out a plan of action to enable low cost, all weather landing system for ill equipped airfields.

We look forward to the workshop deliberations and suggested plan of action.

New Generation Regional Transport Aircraft (RTA-70)

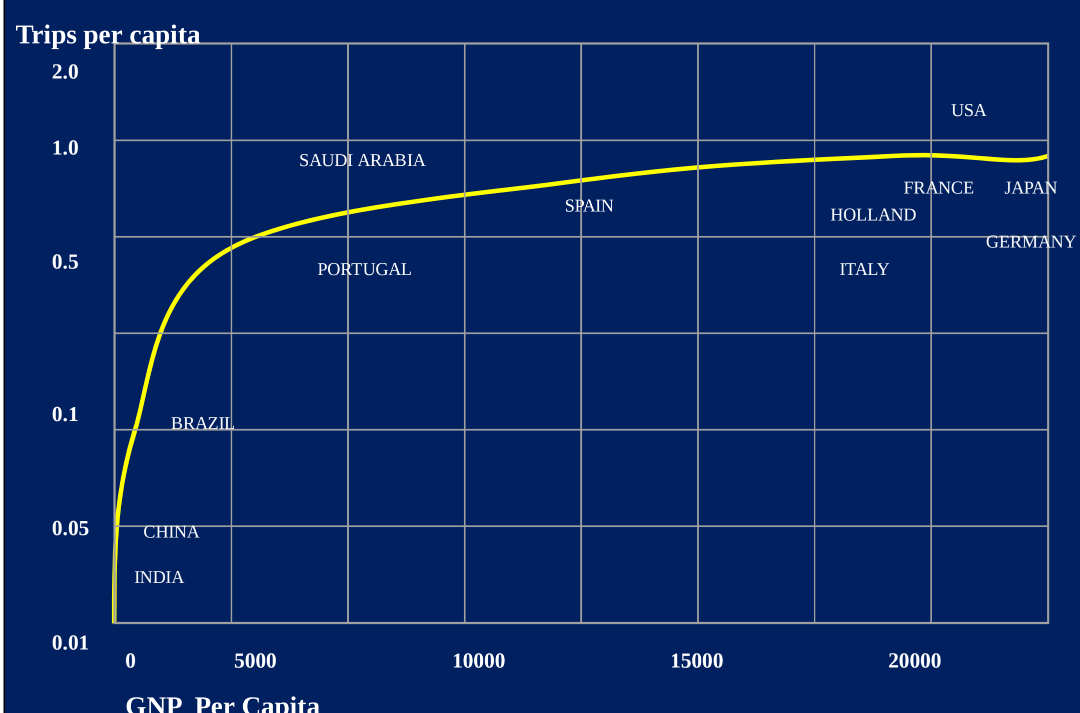
Kota Harinarayana

(Raja Ramanna Fellow)

NAL, Bangalore, India

25-4-2008,NAL

AIR TRAVEL MATURITY



Airports/Airfields in India

- There are 449 airports / airstrips in India
- Currently various Airlines are utilizing only 66 Airports.
- This means there is still a huge market to be tapped in the Civil Aviation sector.

Civil Aviation in India

AFFLUENCE LEVELS

More or less evenly spread out

- Higher levels in the West and South
- Demand pyramid for air travel accessible in all regions, including in the East and North East

AIRPORTS AND AIRFIELDS

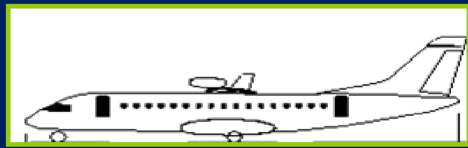
- Major metros > 1000 kms from each other
- Airfields spread out across the country
- Airfields and economic development relationship evident in many areas

PRESENT CONNECTIVITY

Trunk routes (A320,B737)

- Regional networks (B737,A320, ATR42/72)
- Long thin routes CRJ 700
- State level single frequency Operation (ATR/B737,A320)

NEW GEN REGIONAL AIRCRAFT

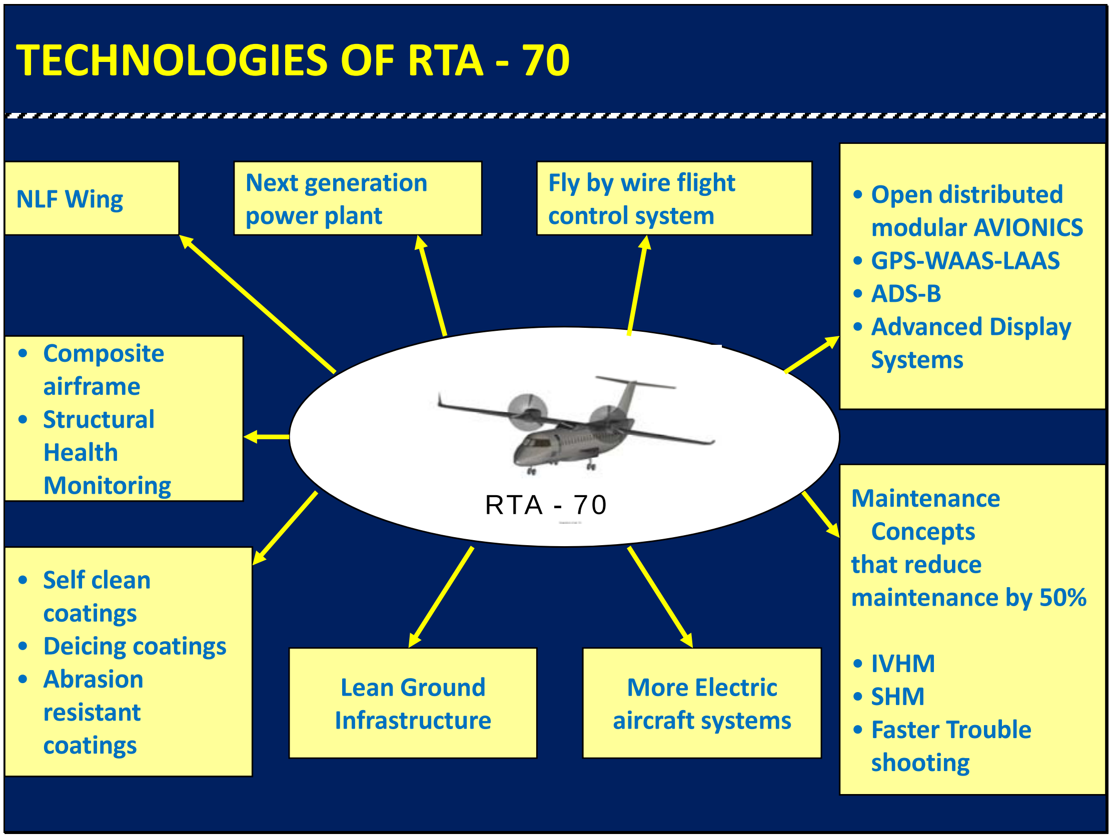


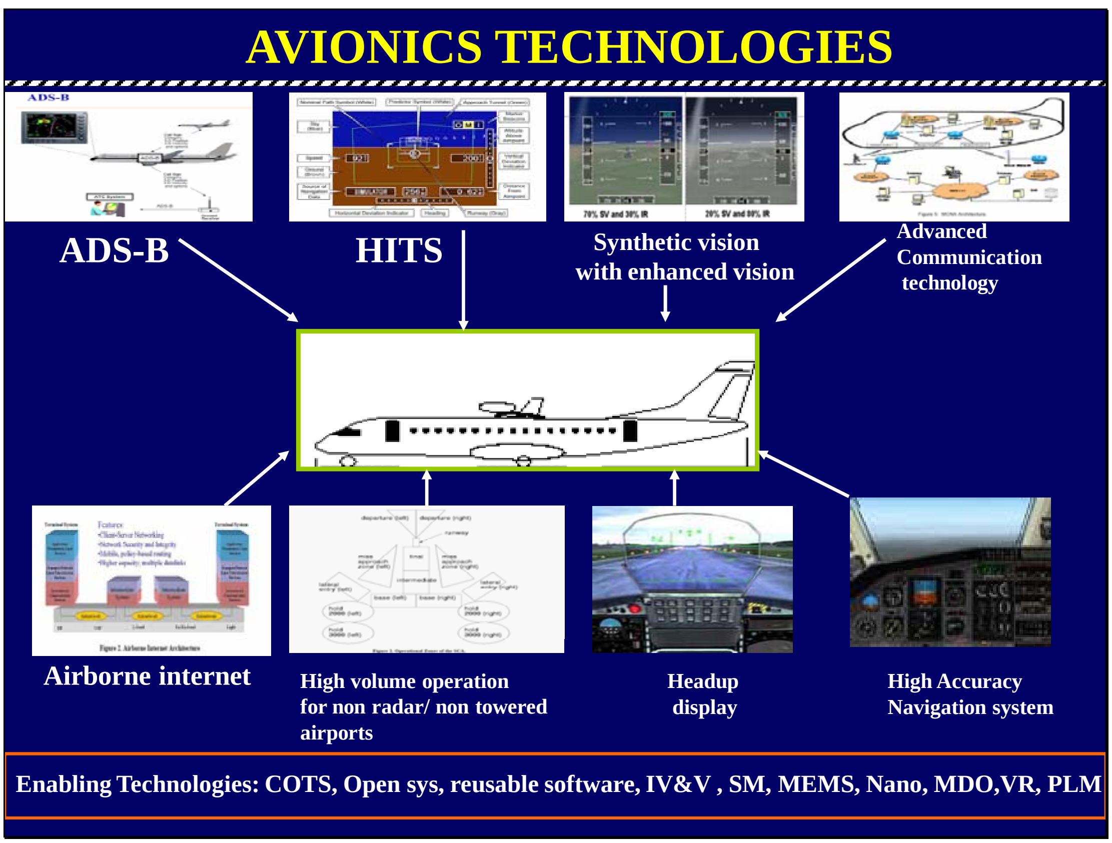
Capabilities:

•Acquition cost :25% lower
•Operating cost : 25% lower
•Maintenance cost : 50% lower

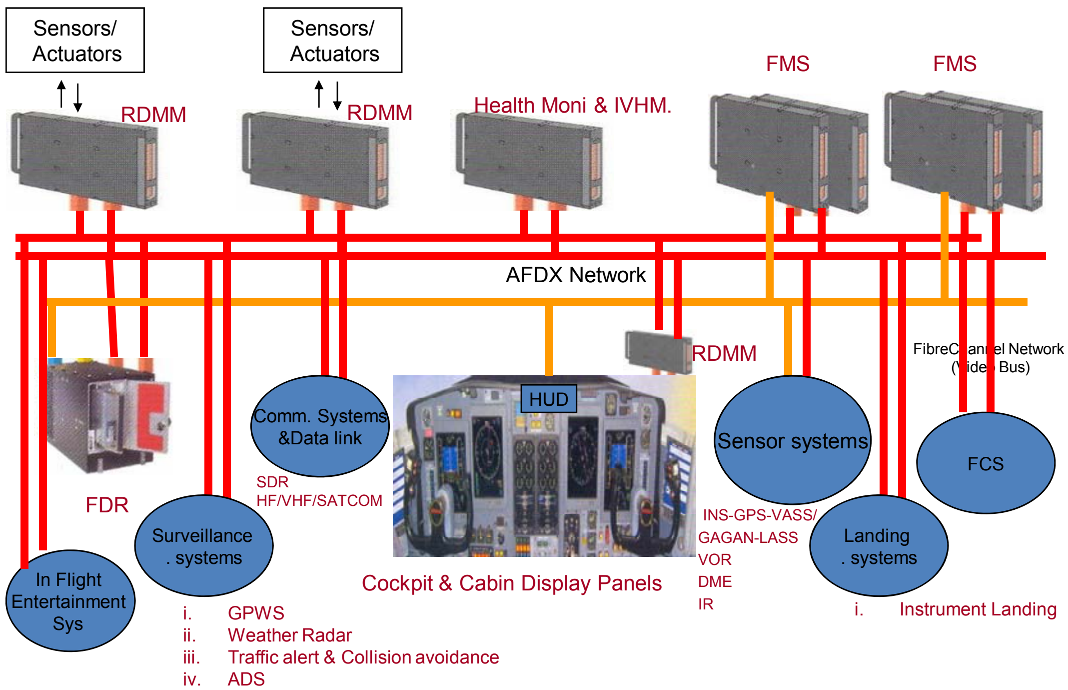
•TO & land from unequipped airfields
•All weather operation
•Enhanced safety

Technology Requirements


TECHNOLOGIES OF RTA - 70
NLF Wing
Next generation power plant
Fly by wire flight control system
• Open distributed modular AVIONICS
• GPS-WAAS-LAAS
• ADS-B
• Advanced Display Systems
• Composite airframe
• Structural Health Monitoring
RTA - 70
Maintenance Concepts that reduce maintenance by 50%
• IVHM
• SHM
• Faster Trouble shooting
• Self clean coatings
• Deicing coatings
• Abrasion resistant coatings
Lean Ground Infrastructure
More Electric aircraft systems


AVIONICS TECHNOLOGIES
ADS-B
HITS
Synthetic vision with enhanced vision
Advanced Communication technology
Airborne internet
High volume operation for non radar/ non towered airports
Headup display
High Accuracy Navigation system
Enabling Technologies: COTS, Open sys, reusable software, IV&V , SM, MEMS, Nano, MDO,VR, PLM

Open Distributed Integrated Modular Avionics



GENERAL OPERATIONAL REQUIREMENTS

1) Safe Operation under all conditions (especially landing) including poor visibility, bad weather conditions & hilly terrain.
2) Provide assistance to pilots during Flight & Landing with improved Situation Awareness (Improved Sensors, Displays –MFD &HUD-& Decision Support Systems- Conflict Detection & Alert Systems)
3) More Automation in all phases of Flight including Cruise, Approach, Landing & Take Off.
4) Improved & Low Cost Maintenance Support in the form of In Flight Health & Condition Monitoring of all Systems & Structures, Trend Monitoring with Improved Diagnostics & Prognostics. Extensive Capability for Off Line Maintenance.

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GENERAL OPERATIONAL REQUIREMENTS
(Contd.)

- 5) Improved & Efficient Data Communications between all Stakeholders including Pilot, ATC, Airlines Operations & Airlines Maintenance. The Communication System should be designed to be a part of ICAO Aeronautical Telecommunication Network (ATN)
- 6) Data Link for uploading Weather Data from Ground Weather Stations/ Radars to the Aircraft for Display in the Cockpit.
- 7) More accurate & Cost Effective Hybrid Navigation Systems including GPS & MEMS based INS augmented with WAAS/GAGAN& LAAS.

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GENERAL OPERATIONAL REQUIREMENTS
(Contd.)

- 8) Provision for the Implementation of Concepts of Reduced Vertical Separation, Self Separation, “Free Flight” & “Agile Airspace Operations” with less dependency on ATC & more responsibility to Pilots using ADS-B Data
- 9) Efficient Surface Management at Airports with use of ADS-B Data, Surface Radars & Multi Sensor Data Fusion

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AVIONICS FUNCTIONALITIES

1. Communication Functions
2. Navigation & Flight Management System (FMS) Functions
3. Aircraft Surveillance Functions
4. Aircraft Landing System
5. Aircraft Health Monitoring & Maintenance Function
6. Display Function & Flight Deck
7. Data Loading Function
8. Utilities Function

All-Weather Terminal Area (ATWA) Operations

Categories of Instrument Approach Procedures

Category	Decision Height (DH, ft.)	Runway Visual Range (RVR, ft.)	Alert Height (AH, ft.)	Equipment allowed
CAT I	DH > 200	RVR > 1800	N/A	N/A
CAT II	200 > DH > 100	RVR > 1200	N/A	N/A
CAT IIIa	100 > DH	RVR > 700	100	Fail-passive & fail-operational
CAT IIIb	50 > DH	700 > RVR > 150	100	Fail-operational
CAT IIIc	CAT IIIc landing has no limit on DH and RVR, but is currently unauthorized			

Why
GPS / WAAS / LAAS?

- **To provide an inexpensive and reliable global area navigation capability.**
  This is the cornerstone of free flight.
- **To provide an inexpensive precision approach capability everywhere.**
  This is a significant safety benefit.
- **To do this, we have to deliver a navigation system capable of these services without reliance on other navigation systems.**
  That is the purpose of WAAS and LAAS.

AVIONICS FUNCTIONALITIES

Aircraft Landing System:

GPS based Landing System up to Cat 3 A shall be provided. Compatibility with LAAS is essential

Appropriate Cues for Landing shall be provided on the HUD to enable Landing under adverse weather conditions.

Improved situation awareness-----Improved and low cost sensors with augmented/synthetic vision along with decision support systems (conflict detection & alerting systems).

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STUDIES ON NEW TECHNOLGIES

1) Studies on use of ADS-B for improved Situation Awareness-both in Air & on Surface

Technologies- Multi Sensor Data Fusion & Software Defined Radio for combined UAT&1090ES

2) Studies on Synthetic & Enhanced Vision & Low cost HUD

3) Operation from Non Radar Airspace & Non Towered Airport- CON OP of Self Controlled Area, Conflict Detection & Alert System & Decision Support System

4) Study of Data link for Transmission of Weather information from Networked Ground Weather Radar Stations.

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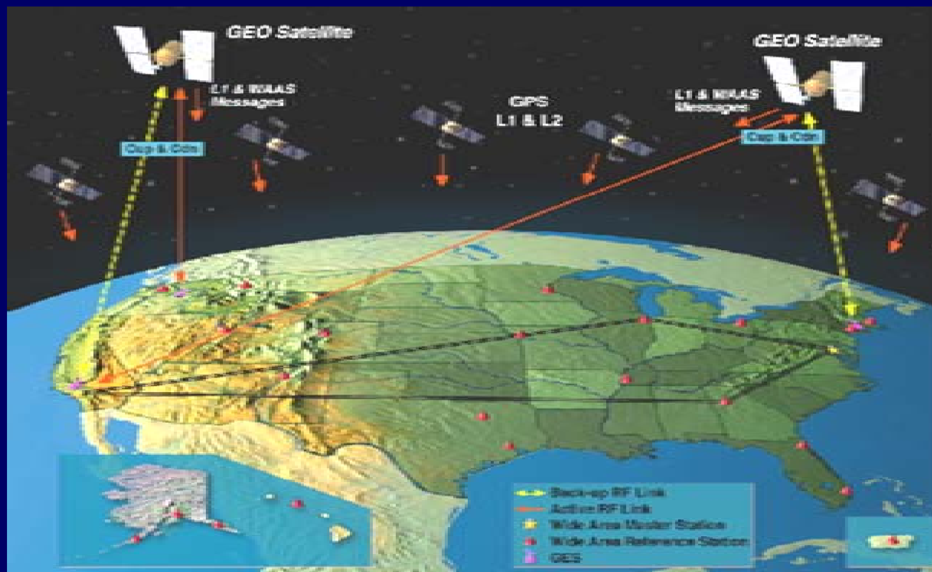
- ***WIDE AREA AUGMENTATION SYSTEM (WAAS)***

- **Local Area Augmentation System (LAAS)**
- **Johns Hopkins University Applied Physics Laboratory (JHU APL) Independent Risk Assessment**
- **Investment Analysis**
- **International Cooperation**
- **Summary Points**

WAAS Architecture



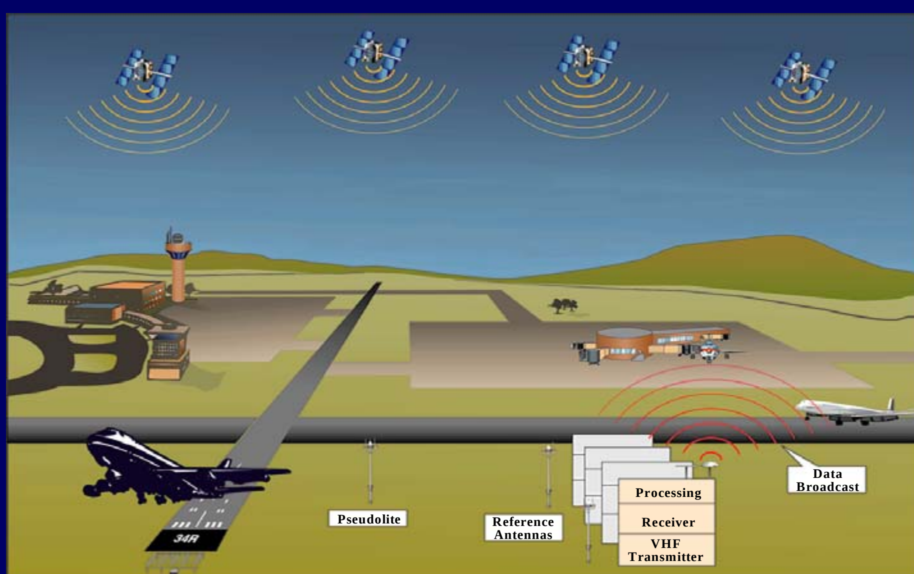
WAAS
IOC Benefits

- En route through non-precision approach
  - **Available throughout entire service area**
  - **Raytheon implementation 99.9% availability**
  - **Subject to availability of FAA provided GEOs**
  - **Potential to replace VOR/DME/NDBs in NAS**

WAAS
IOC Benefits
(continued)

- Precision approach
  - **Coverage for approximately 50% of CONUS airports**
  - **Service provided in central regions of CONUS**
  - **Implementation designed to support 95% availability**
  - **Further enhancements needed to replace existing precision approach systems**

LAAS Ground Segment



LAAS
Benefits

LAAS Benefits	ILS Benefits
• Less expensive user equipment (quantified) • Less expensive ground (FAA) equipment (quantified) • Shortened approach paths (partially quantified) • Lower FAA maintenance costs (quantified) • Surface navigation (not quantified) • New approach, guided departure, guided missed approach procedures (not quantified) • Rotary wing precision approach (not quantified)	• Sunk cost for existing systems (quantified)

All-Weather Terminal Area (ATWA) Operations

Basic Types of AWTA approach and landing operations

1. Visual Approach
   - Aircraft is being operated in normal visual flight rules (VFR) and normal instrument flight rules (IFR)
2. Instrument Approach
   - Instrument approach procedures permit descent in IFR conditions to allow for a safe landing.
   - Standard instrument approaches include International Civil Aviation Organization (ICAO), standard Navigation Aids (ILS, MLS, VOR, VOR/DME, NDB), as well as approaches based on ATC radar services.

All-Weather Terminal Area (ATWA) Operations (cont'd)

Requirements for VFR (FAR Part 121.649)

1. Regardless of ATC clearance, no pilot may takeoff or land when the reported ceiling and visibility is less than:
   - Day Operation: 1,000 ft ceiling and 1 mile visibility
   - Night Operation: 1,000 ft ceiling and 2 mile visibility
2. Where local surface visibility restrictions exist (smoke, dust, blowing snow, etc.) the visibility for day and night operations may be reduced to ½ mile provided all flight beyond 1 mile from the airport can be accomplished outside of the surface visibility restriction.

All-Weather Terminal Area (ATWA) Operations (cont'd)

Requirements for IFR (FAR Part 121.651)

1. Prior to takeoff, the pilot must obtain ATC clearance and must pass weather conditions specified in operation specifications manual take-off minimums.
2. Prior to the final approach segment of the instrument approach, the destination airport must issue a weather report with above-minimum weather conditions for the pilot to pass the final approach fix.
3. If the pilot has entered the approach and an updated weather with below-minimum weather conditions, the pilot may continue until decision height.
   - At the DH, the pilot may continue to touch down if:
     - ➢ A normal touchdown will occur within the touchdown zone.
     - ➢ The flight visibility agrees with the instrument approach procedure being used
     - ➢ In a category I approach, one of the following visual references must be identified:

All-Weather Terminal Area (ATWA) Operations (cont'd)

Requirements for IFR (FAR Part 121.651) (cont'd)

- The threshold
- The threshold markings
- The threshold lights
- The runway end identifier lights
- The visual approach slope indicator
- The approach light system
- The touchdown zone or touchdown zone markings
- The touchdown zone lights
- The runway or runway markings
- The runway lights

Electronics

- **Air Traffic control (ATC)**
  - **Better weather prediction and detailed weather reports**
  - **Pilots must be informed of landing conditions (wind speed/direction, runway surface conditions)**
- **Auto-pilot can execute landings in conditions of poor visibility that would be impossible otherwise**
  - **Sophisticated systems can also execute landings in severe crosswind conditions**
- **Technology to improve visibility**
  - **Fog defeating system converts signals from on-board sensors and airport navigational aids into a holographic image of the approaching runway, which is projected onto a glass screen between the pilot and the windshield.**

Speaker Profile

Dr. Kota Harinarayana was born in Berhampur, Orissa, in 1943 and graduated from BHU in Mechanical Engineering, post-graduate in Aero Engineering at IISc, Bangalore. He did his Ph.D. at IIT Bombay and also he is holding a Bachelor's degree in Law. He started his career in 1967 at HAL. He moved to DRDO HQ in 1970 till 1982 and held various positions. He rejoined HAL in 1982 as Chief Designer in Nasik Division. He was deputed to DRDO in 1985and assumed charge as Director, ADE, Bangalore.

He was appointed as LCA Programme Director in December 1985 and he was concurrently holding the post of Director, ADE till June 1986. During 1995 he was elevated as Distinguished Scientist by DRDO. As Programme Director and Chief Designer of Light Combat Aircraft, he successfully directed the project leading to flight testing and clearance for limited series production. Thanks to his efforts, India succeeded in developing a state-of-art, high technology fighter aircraft of world class. He is the Fellow of Aeronautical Society of India (former President of the Society) and Indian National Academy of Engineering. He received distinguished alumnus award from Aerospace Department, IISc in 1993 and from IIT Bombay in 1995. He was awarded National Aeronautics Prize and FIE Foundation Award in 1996. He received SBI-Pragna Puraskar in 2001. He received the Dr. Y. Nayudamma Memorial Award for 2001. He received the DRDO Technology Leadership Award for 2001. He was honoured with Padma Shri by Government of India in 2002. He received Gujar Mal Modi Science foundation award for the year 2006.Indian National Academy of Engineering conferred up on him, the life time contribution award in Engineering, for the year 2006. At present he is the Raja Ramanna Fellow at National Aerospace Laboratories, Bangalore. He was formerly Vice-Chancellor of University of Hyderabad till 15 July, 2005. He is also Chairman, Research Council, Central Scientific Instruments Organization (CSIO), Chandigarh; Chairman, Governing Council, Society for Indo-German Institute of Advanced Technology, Visakhapatnam, Distinguished Guest Professor, Department of Aerospace Engineering, IIT-Bombay.

Keynote Address: Enhanced and Synthetic Vision with WAAS/LAAS for Transport Aircraft

Dr. S V Kibe, Programme Director, SATNAV, ISRO

An aircraft ability to conduct flight operations depends on weather, visibility conditions and the Communication, Navigation and Surveillance (CNS) instrumentation available onboard. With the increasing use of the Global Positioning System (GPS) instrumentation the enroute, approach and landing navigational requirements are met by Satellite based systems and their space and ground based augmentations.

The Wide Area Augmentation System (WAAS) is being implemented over the US National Air Space (NAS), the European Geostationary Navigation Overlay System (EGNOS) over Europe, the MTSAT Augmentation System (MSAS) over Japan and the GPS Aided GEO Augmented Navigation (GAGAN) system over the Indian Air space. The Wide Area Differential Systems provide position accuracy upto CAT-I landing requirements. For increased navigational accuracy leading to CAT-II and III landing requirements, Ground Based Augmentation Systems are essential. The SBAS and GBAS systems have been approved by the International Civil Aviation Organisation (ICAO) for civil aviation.

For surveillance, the Automatic Dependence Surveillance-Broadcast (ADS-B) is yet another aid in facilitating easier and coordinated navigation in the skies. Aircrafts fitted with ADS-B are able to transmit their position to all aircrafts over a given airspace enabling closer spacing and greater situational awareness to the pilot. The currently published ADS-B manual by Federal Aviation Administration (FAA) document No. FAA-2007-29305 dated October 2007 on on Automatic Dependence Surveillance Broadcast (ADS-B) Out performance requirements to support Air Traffic Control (ATC) service states on page 38 that presently GPS augmented by WAAS is the only navigation position source that provides the level of accuracy and integrity to enable ADS-B out to be used for National Air Space (NAS) of US based operations with sufficient availability.

The potential now exists to overcome the low visibility situation near an airport by enhancing the visual references for the flight crew or providing with artificial graphical depictions of visual references. Enhanced flight vision systems help mitigate reduced visibility as a limiting factor in flight operations.

Forty years ago, there were two separate sources of flight information: the panel instruments (head down display) and the out-of-the-window scene (head up display). Gyroscopic instruments and precision ground based radio navigation aids such as DME, ILS and MLS were developed for precision ground based radio navigation aids. Today’s technology has blurred the separation between panel instruments and out-of-the-window scenes as sources of flight information.

Enhanced Vision (EV) is an electronic means to provide a display of the external scene by use of an imaging sensor such as, a Forward Looking Infra-Red (FLIR) or Milli Meter Radar (MMR). Synthetic Vision (SV) is a computer-generated image of the external scene topography generated from aircraft attitude, high precision navigation and data of the terrain, obstacles, cultural feature and other required flight information. SV provides significant improvements in terrain awareness and reductions in the potential for controlled – flight – into – terrain incidents/accidents compared to current cockpit technologies.

The EVS technologies do not use Geo-spatial data bases but use imaging sensors to “see” the environment in front and along the flight path. Enhanced Flight Vision Systems (EFVS) requires a conformal Heads-Up-Display (HUD) or an equivalent display along with specific aircraft flight symbology for operational credit. Alternatively, Head Down Displays (HDD) of EVS are used in some light aircraft and helicopters for general hazard awareness and not allowed operational credit.

These revolutionary crew-vehicle interface technologies strive to pro-actively overcome aircraft’s safety barriers that would otherwise constrain the full realization of the next generation air transportation system.

The NASA Langley Research Centre, Rockwell Collins, Boeing Company and many other leading research laboratories in the US have conducted pilot simulation experiments to evaluate the complementary use of synthetic and enhanced vision technologies. The experimental data showed that significant improvements in situation awareness without con-comitant increases in work load and display clutter could be provided by the integration and/or fusion of synthetic and enhanced vision technologies to increase the ability of the crew to handle substantial navigational errors and runway incursions.

All navigational aids can provide the necessary increased positional accuracies provided the position of the aircraft is known in a standard world geodetic system such as, the WGS-84. The combination of GPS aided navigation and surveillance together with enhanced synthetic vision is the key to all weather commercial aviation operations.

These technological and systemic changes are being developed to increase the capacity, safety, efficiency and security for the Next Generation Air Transportation Systems (NGATS).

While a degree of success in developing these aids has been met, technology for “perfect” object detection and data based / navigation error detection does not yet exist. Further, there may also be gaps, which may still warrant flight deck procedures and human interventions for integrity and error checks. Some of the key technologies in achieving enhanced synthetic vision systems are the Digital Elevation Model (DEM) and the Digital Elevation Terrain Data (DETD). The Terrain Data Base, Obstacle Data Base and Navigation Data is used for a 3-dimensional image construction which is further aided by aircraft navigation, payload sensor and net-centric data sources which feed into the flight management system.

Workshop on Enhanced & Synthetic Vision for Transport Aircraft

Keynote Address

By

Dr. S.V. Kibe
Programme Director, SATNAV
ISRO Headquarters
Bangalore, India

NAL, Bangalore

25 – 26, April 2008

HUD in a Pontiac Bonneville showing a speed of 47 mph

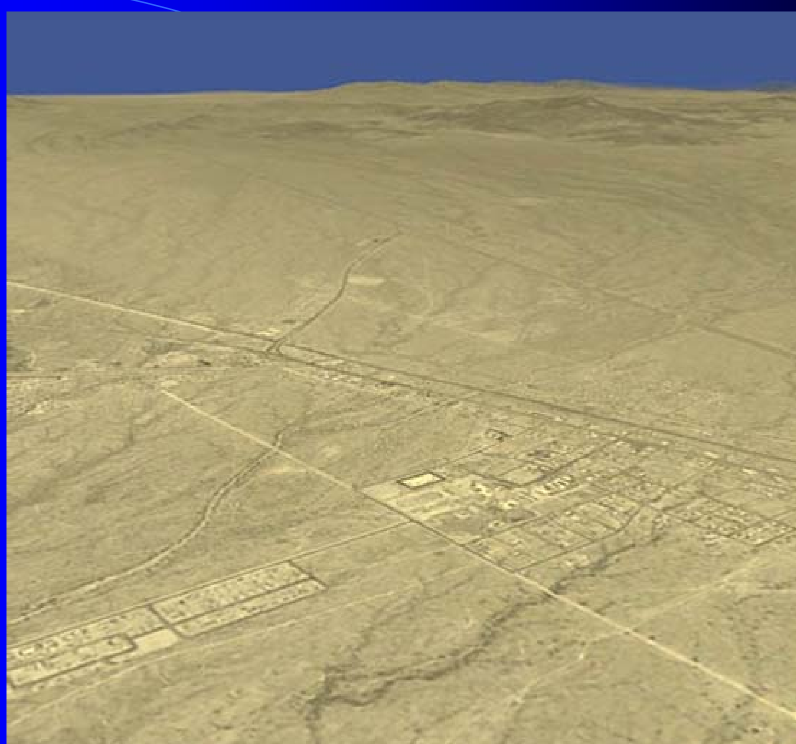
Synthetic Vision Systems (SVS)

•Synthetic Vision Systems (SVS) can provide an aid for runway location or other objects, make visual search for specific features more efficient, and facilitate future action planning in dynamic environments

•Synthetic vision is a computer-generated image of the external scene topography from the perspective of the flight deck, derived from aircraft attitude, high-precision navigation solution, and database of terrain, obstacles and relevant cultural features.

•A synthetic vision system is an electronic means to display a synthetic vision image of the external scene topography to the flight crew.

•SVS does not include flight guidance cues but is typically integrated with such cues as well as other strategic information typically found on a navigation display.

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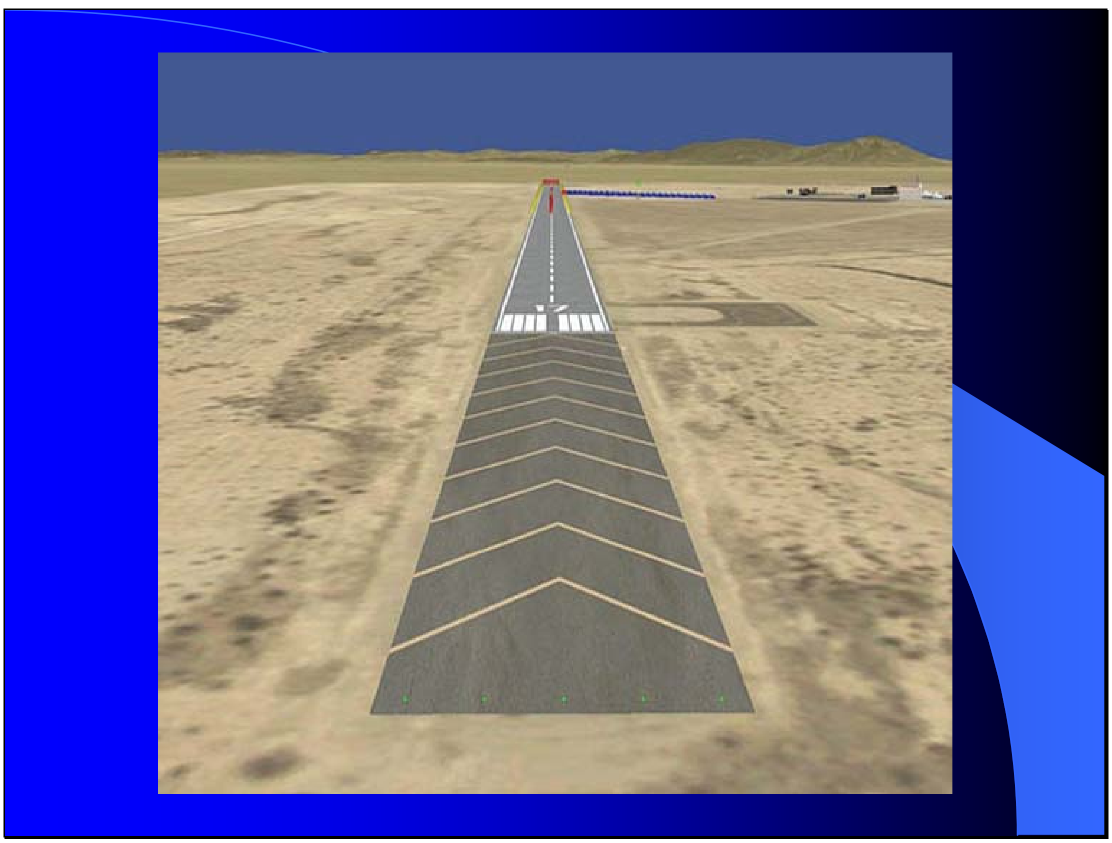
For Help, press F1
Zoom:1/2



Enhanced Flight Vision Systems

- Enhanced Flight Vision Systems (EFVS) help mitigate reduced visibility as a limiting factor in flight operations.
- EVS technologies do not use geo-spatial databases, but use imaging sensors (e.g., infrared) to “see” the environment in front of and along the flight path. EVS technologies have been certified on many platforms with varying levels of complexity.
- For example, EFVS requires a conformal Heads-Up Display (HUD), or an equivalent display, along with specific aircraft flight symbology, EFVS sensor imagery, attitude symbology, and guidance appropriate for the approach to be flown for operational credit.
- Head down displays (HDD) of EVS are used in some light aircraft and helicopters for general hazard awareness and are not allowed operational credit.

Head-Up Displays (HUDs)

- There are two types of HUDs – Fixed & Helmet mounted.
- Fixed HUDs require the pilot to look through a display element attached to the airframe or vehicle chassis.
- Helmet mounted HUDs feature a securely attached display element that moves with the orientation of the user’s head.
- Several display technologies are used such as, Liquid Crystal Display (LCD), Liquid Crystal on Silicon (LCoS), Digital Micro Mirrors (DMM) & Organic Light Emitting Diodes (OLED).

HEAD-UP DISPLAY OF AN F/A-18C MILITARY AIRCRAFT

Co-Pilot's HUD of a C-130J


(SVS)
Rockwell Collins
FAA
TUDelft
JEPPESEN
Rockwell Collins

A synthetic vision system display

Symbology

- **Boresight** symbol is fixed on the display and shows where the nose of the aircraft is actually pointing.
- **Flight Path Vector (FPV)** symbol shows where the aircraft is actually going.
- **Acceleration** indicator symbol shows whether the aircraft is accelerating or decelerating.
- **Registration** or accurate overlay of the EVS image with the real world image is important particularly during approach and landing guidance and uses ILS, GPS WAAS & Other Navigation systems which typically provide a circle which fits inside the FPV symbol.

RTCA SPECIAL COMMITTEE 213 FOR EFVS & SVS

•RTCA Special Committee will develop MASPS-level guidance for Synthetic Vision Systems (SVS), Enhanced Flight Vision Systems (EFVS), Enhanced Vision Systems (EVS) and combined SVS/EFVS and SVS/EVS architectures to identify the intended operations and system architectures and enable development of Minimum Operational Performance Standards for appropriate system components.

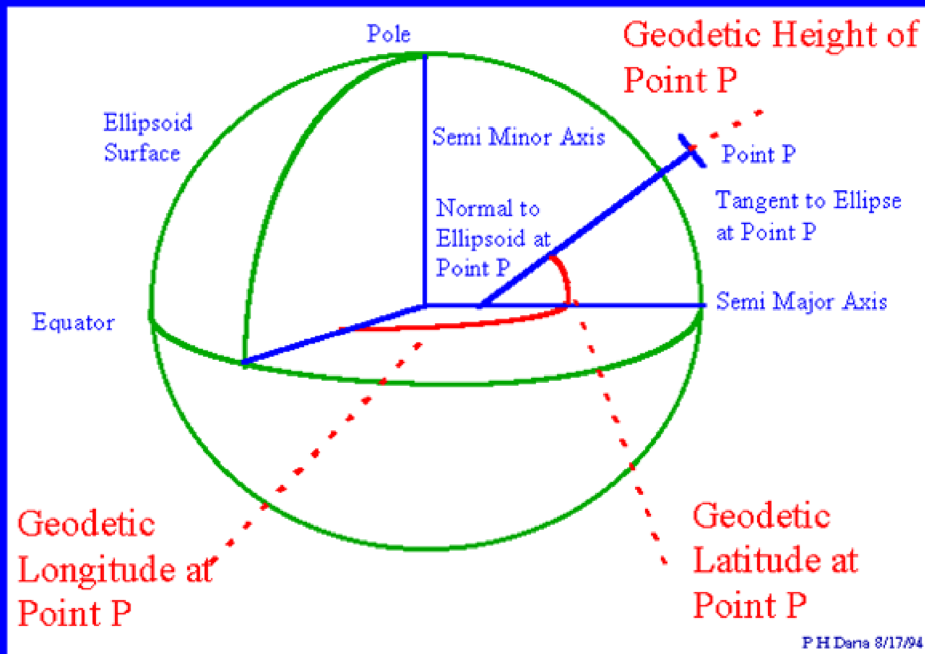
•The MASPS shall not contradict nor conflict with existing FAA certification criteria established and applied to existing SVS and EVS product approvals.

•The MASPS shall not contradict nor conflict with existing FAA certification criteria established and applied to existing SVS and EVS product approvals.

Certification of EFVS/SVS

- While the EFVS & SVS displays are a great help, FAA has only "relaxed" the operating regulations where an aircraft with EVS operating can perform a Cat.I approach to Cat.II minimas. The reluctance is due to the fact that a lot more confidence needs to be built where the pilot has a very short period of time to (a) take in the reality of what is displayed is not what is real. (b) decide that action needs to be taken (c) take action & (d) allow the airplane sometime to respond. Essentially, these worries come from the registration accuracy & the ability of the displays to be as close to reality as possible..

WGS-84 ELLIPSOID



Geodetic System, Atomic Time Standards & Centre Frequency of transmission

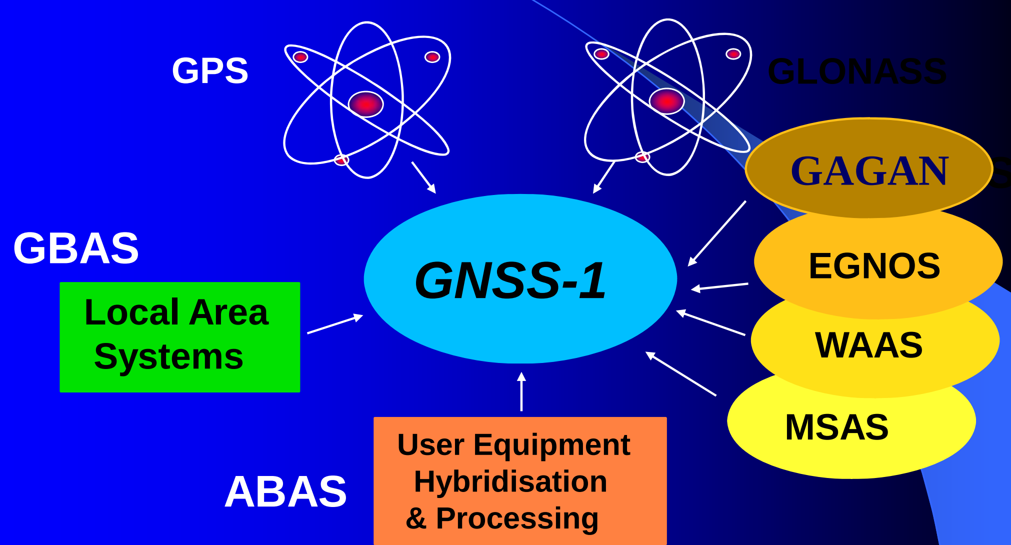
- Position accuracy of an aircraft using satellite based navigation system is dependent on

1. Geodetic reference frame & its coincidence with International Terrestrial Reference Frame (ITRF).
2. The system time & its difference with UTC
3. Centre frequency of transmission if the position solution takes satellites from different systems.
4. The feuditial reference point and their representation on the Geodetic Reference Frame determines the registration of the aircraft position vis-à-vis the airport during precision approach and landing.

Key Research Institutes

- NASA AMES Research Centre & Langley Labs
- Rockwell Collins
- Boeing Company
- 3D Vision Systems
- San Jose State University
- University of Illinois
- Technical University of Delft, Netherlands
- Jeppessen

EGNOS: The European GNSS1 Element

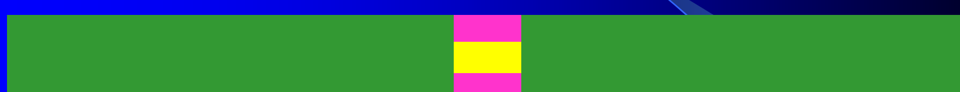


WIDE AREA DIFFERENTIAL TECHNIQUE

SEPARATION OF ERRORS

ATMOSPHERIC ERROR - 3D
EPHEMERIC ERROR - 3D
CLOCK ERROR - 1D

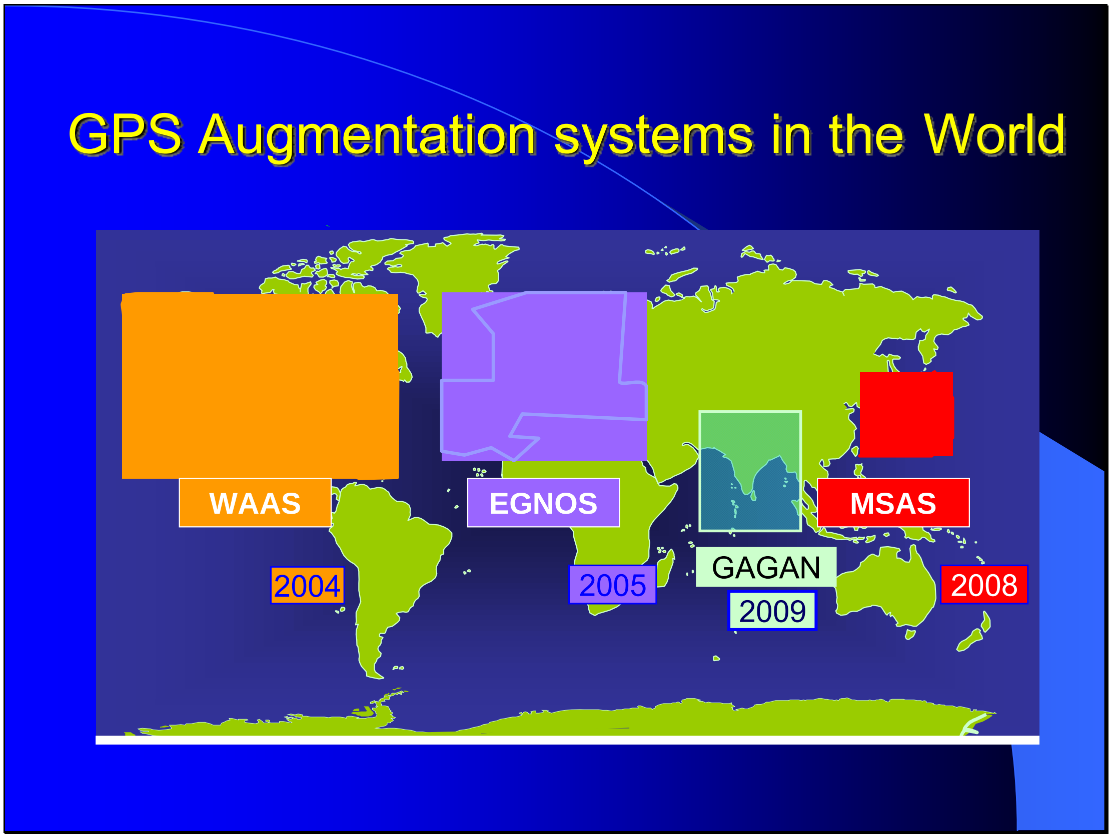
Performance Comparison

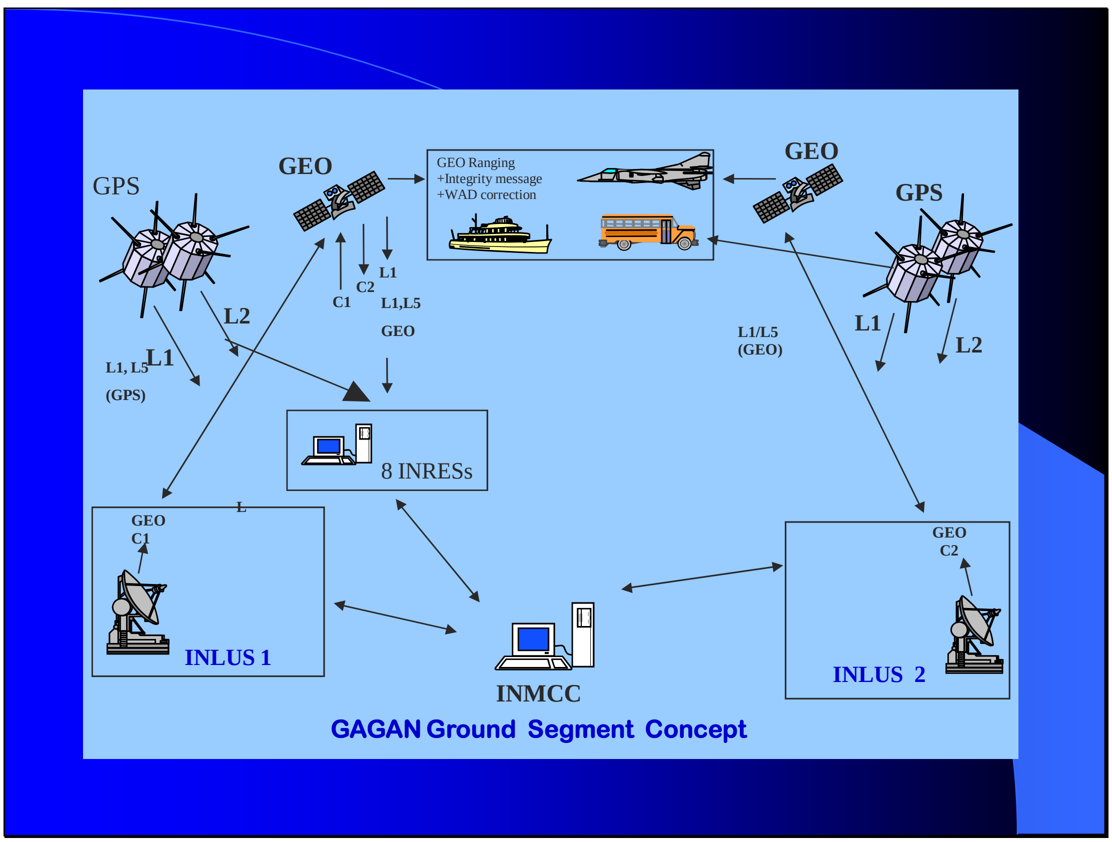


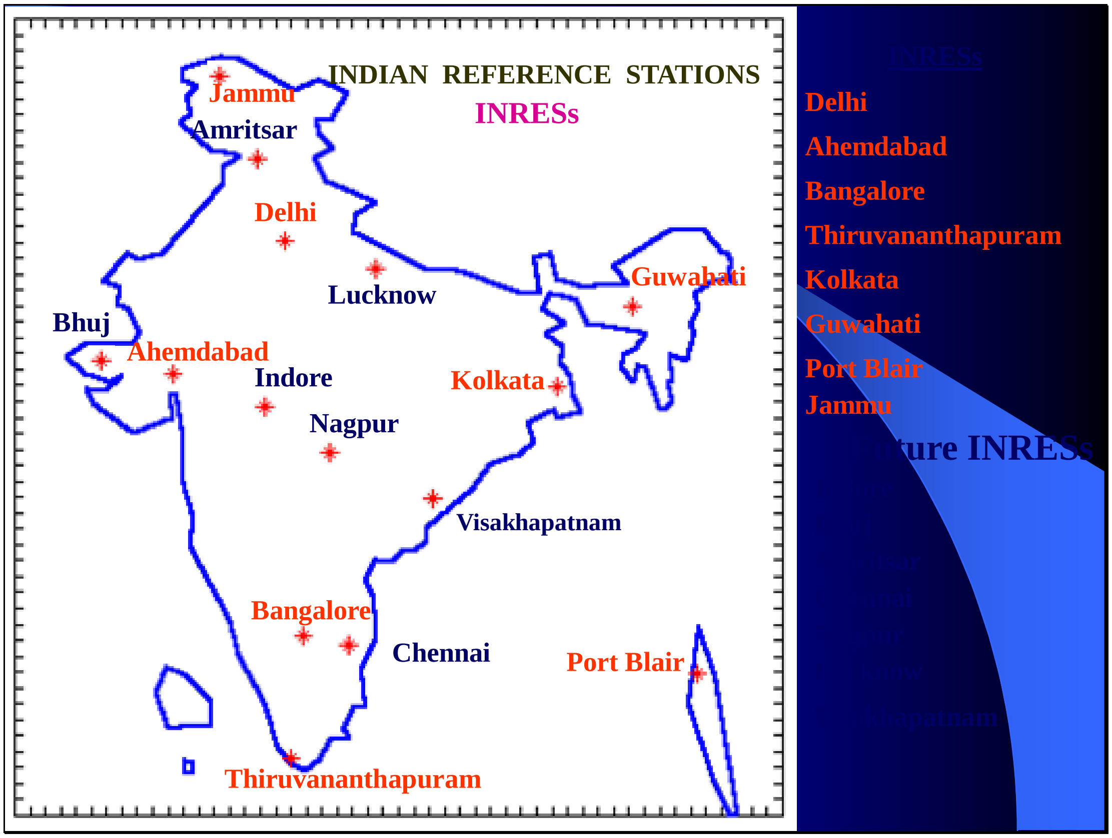
LNAV/VNAV (556 m by 50 m) - Baro VNAV

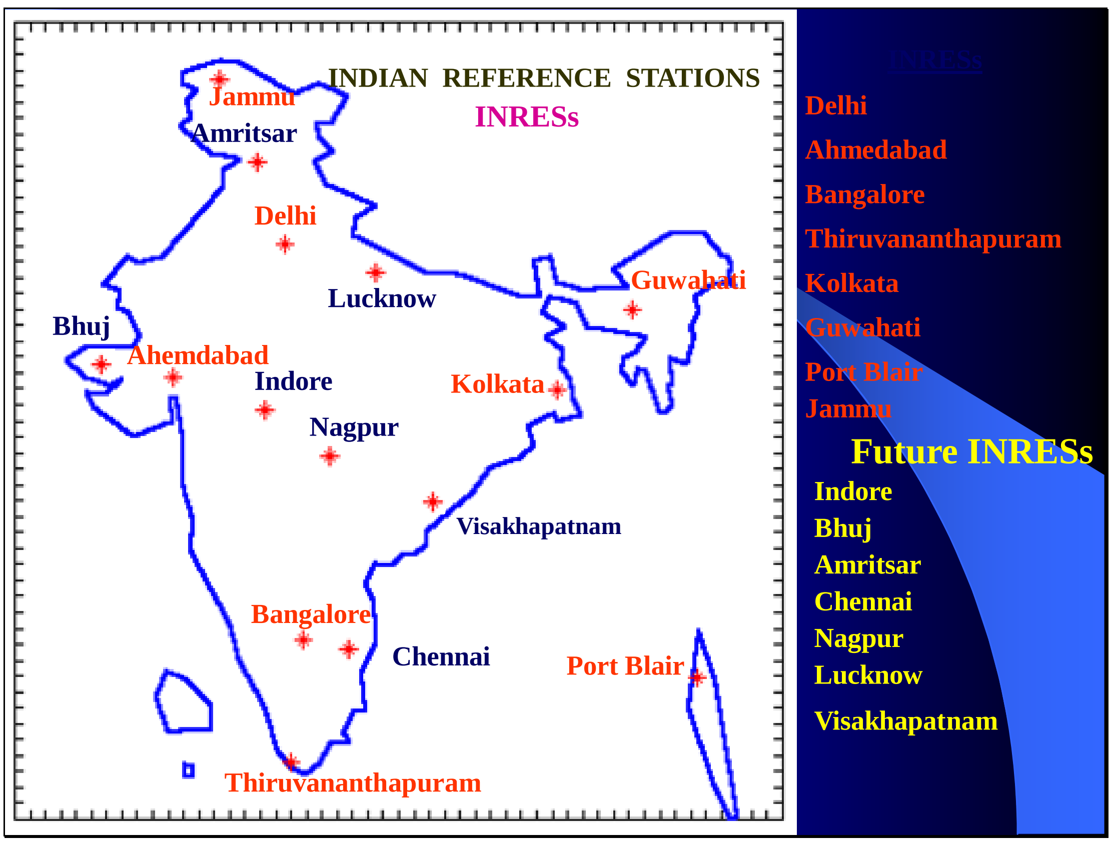
New APV-I (40 m by 50 m) - SBAS Avionics

APV-II (40 m by 20 m) - SBAS Avionics


GPS Augmentation systems in the World
WAAS
EGNOS
MSAS
GAGAN
2004
2005
2009
2008


GPS
GEO
GEO Ranging
+Integrity message
+WAD correction
GEO
GPS
L2
L1, L5
L1
(GPS)
C1
C2
L1
L1,L5
GEO
L1/L5
(GEO)
L1
L2
8 INRESs
GEO
C1
INLUS 1
GEO
C2
INLUS 2
INMCC
GAGAN Ground Segment Concept


INDIAN REFERENCE STATIONS
INRESs
Jammu
Amritsar
Delhi
Lucknow
Guwahati
Bhuj
Ahemdabad
Indore
Kolkata
Nagpur
Visakhapatnam
Bangalore
Chennai
Port Blair
Thiruvananthapuram
Delhi
Ahemdabad
Bangalore
Thiruvananthapuram
Kolkata
Guwahati
Port Blair
Jammu


INDIAN REFERENCE STATIONS
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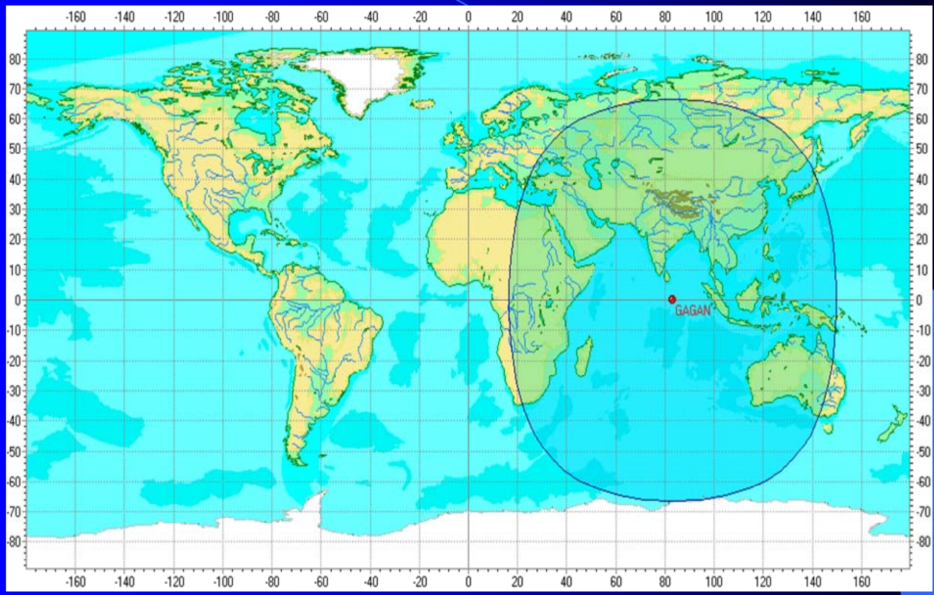
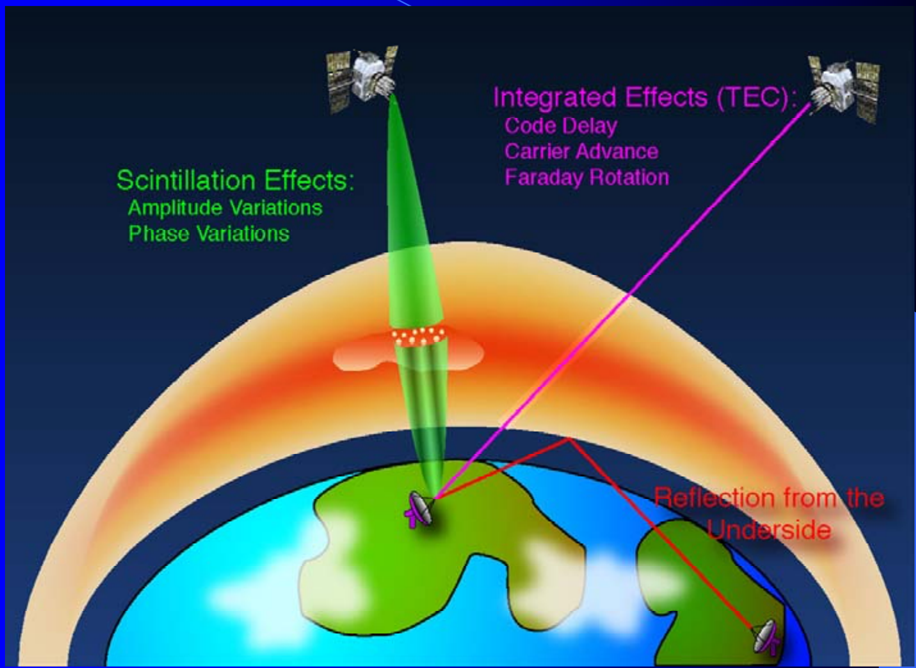
Kolkata
Nagpur
Visakhapatnam
Bangalore
Chennai
Port Blair
Thiruvananthapuram
Delhi
Ahmedabad
Bangalore
Thiruvananthapuram
Kolkata
Guwahati
Port Blair
Jammu
Future INRESs
Indore
Bhuj
Amritsar
Chennai
Nagpur
Lucknow
Visakhapatnam

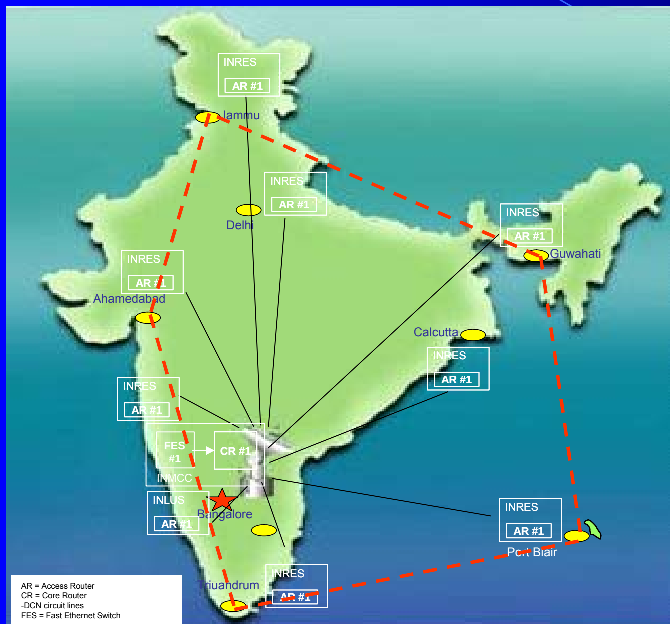
COVERAGE FROM 82 Deg.E



Ionospheric Effects



FSAT completed with GAGAN-TDS configuration (13-14 Aug 2007)



Ground Segment

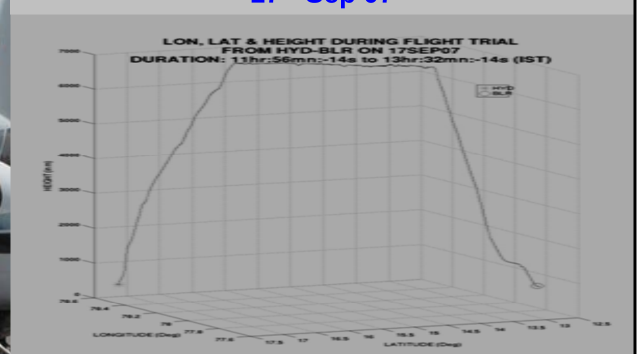
- 8 INRES: 2 INREEs
- 1 INMCC
- 1 INLUS
- 1 ring of OFC (7 INRES)
- 1 VSAT link (GPB)

Space Segment

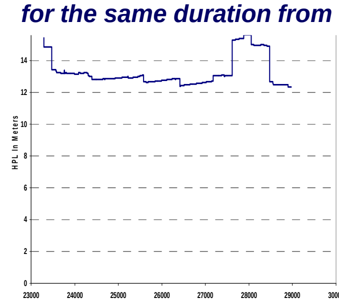
- INMARSAT-4F1

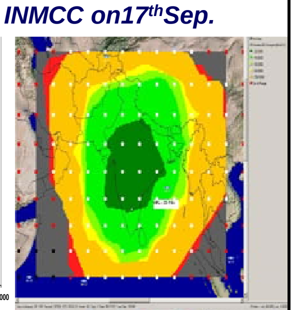
- Accuracy was evaluated within the perimeter of the GAGAN-TDS INRES (GBG, GDP, GCC)
- FSAT performance analysis through RT-GAINS completed

Flight Path from Hyderabad to Bangalore on 17th Sep 07



HPL computed for the flight path and HPL contour for the same duration from INMCC on17th Sep.

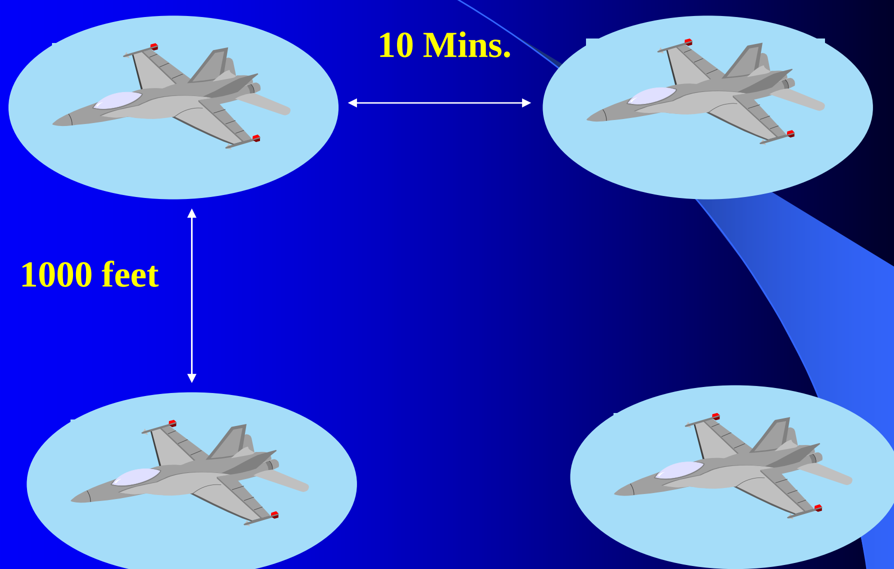




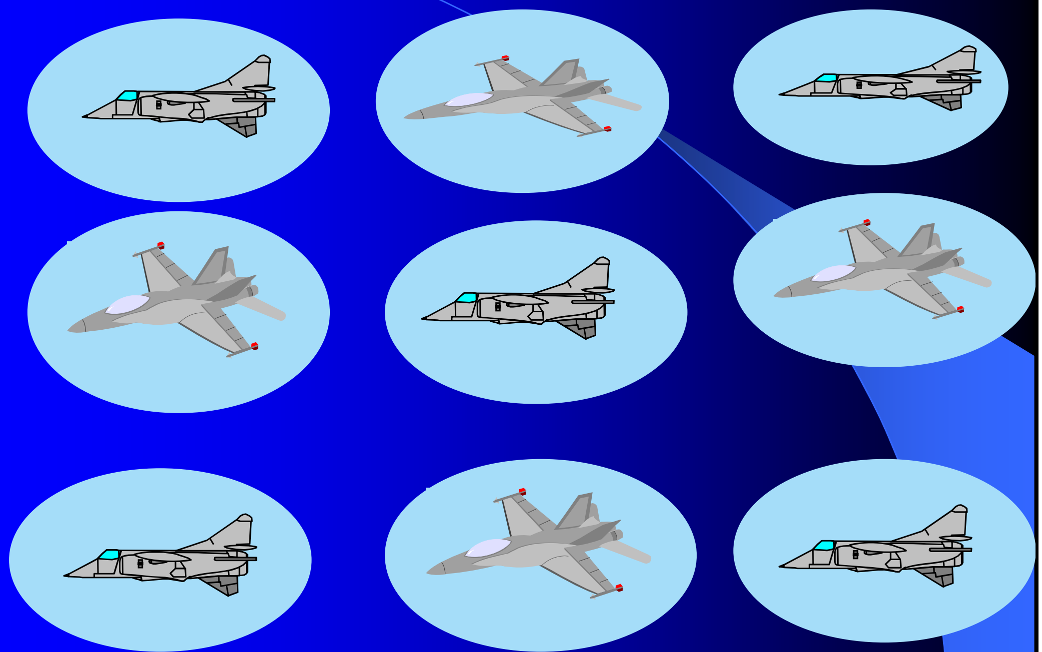
WAAS Avionics

- Two Certified Receivers Currently Available
  - Garmin & Chelton Systems (With Free Flight Systems WAAS Sensor)
  - Over 4,000 Garmin GNS-480 Sold
- In Development
  - Garmin 430/530 Upgrade – Available Summer 2006
    - 50,000 units eligible for upgrade
  - Chelton, Universal, Thales, and Honeywell expect to have units available in 2006
- FAA Funding Development of Rockwell Collins Unit
  - Supports FMS and regional jets
  - Available November 2006
- Others in Development

PRESENT

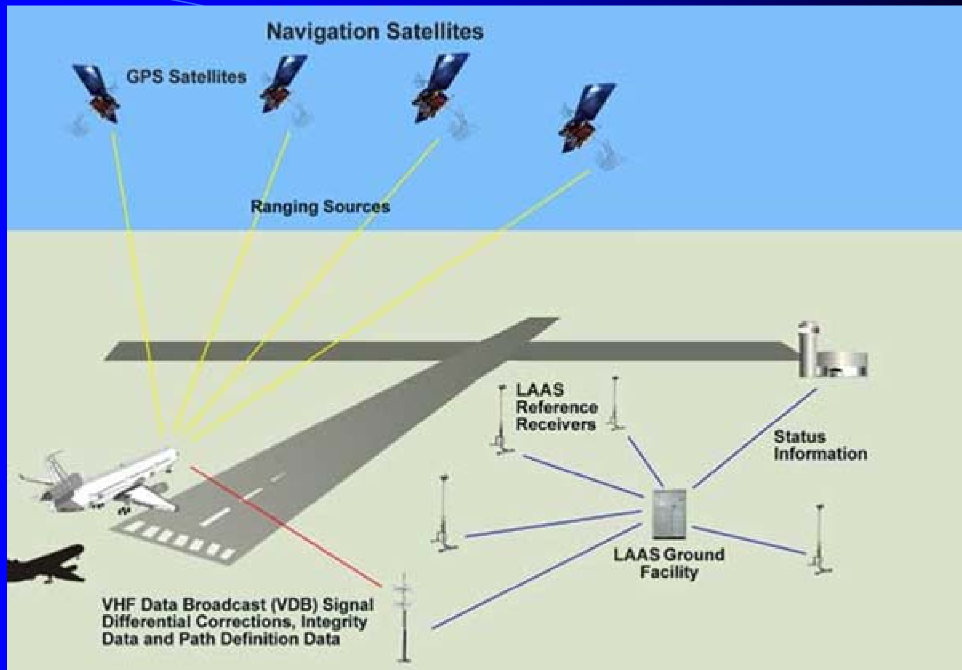


FUTURE WITH ADS-B

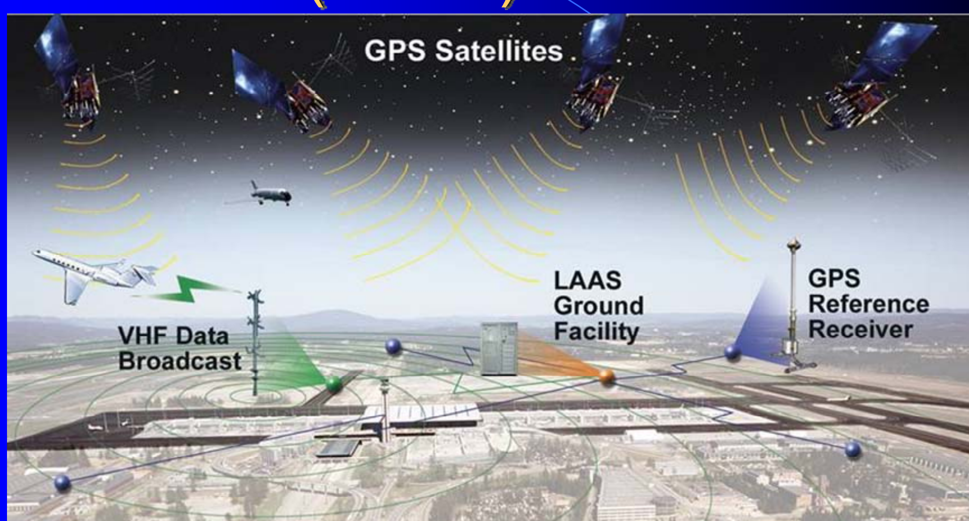


FAA's GNSS Activities

- U.S. Has Approved Use of Global Positioning System (GPS) For Aircraft Navigation For Over A Decade
- FAA Working With Other U.S. Federal Government Agencies To Ensure Modernization of GPS Improves Aviation Capabilities
- FAA Has Commissioned the FAA's GNSS Space Based Augmentation System (SBAS)
  - Wide Area Augmentation System (WAAS)
- FAA Is Continuing Development Of the GNSS Ground Based Augmentation System (GBAS)
  - Local Area Augmentation System (LAAS)
- FAA Has Committed To A "Performance Based National Airspace System"
  - Fully utilize the capabilities of all equipment aboard the aircraft
  - Implement Required Navigation Performance (RNP)



GBAS (LAAS) Architecture



LAAS Capabilities

- The Local Area Augmentation System (LAAS) Represents the U.S. Approach to the International Goal of an Interoperable GBAS Capability
- LAAS Provides a Navigation Signal That Supports the Most Demanding RNP Requirements
- LAAS Provides Service Beyond SBAS Limitations
- One LAAS Can Cover the Entire Terminal Area and Enables Precision Guidance
  - All Runway Ends
  - Multiple Landing Points
  - Surface Movements

WAAS – GLS Development

- Commencing In 2008
- GLS Capability Will Require Modernized GPS Constellation
  - Addition Of Second Frequency, L5
  - Availability Of L5 For Operational Use By Aviation Expected By 2013
  - FAA Ground Upgrade Complete In 2013
- Hardware:
  - Upgrade of Reference Station Receivers To Receive L5
- Software:
  - Broadcast Of WAAS Message On L5
- Eliminates Loss Of Vertical Guidance Caused By Ionospheric Storms
- Provides Full GLS Capability Throughout Coverage Area
- Capable Of Augmenting Other Satellite Navigation System Constellations


FREE FLIGHT REQUIREMENTS
BETTER COMMUNICATION, NAVIGATION AND SURVEILLANCE & UNIVERSALLY ACCEPTABLE WORLD GEODETIC-COORDINATE SYSTEM
NOW
FREE FLIGHT
COMMUNICATIONS
HF/HF LINKS (VOICE)
DIGITAL VHF (VOICE + DATA)
SATCOM (VOICE + DATA)
NAVIGATION
NDB,VOR,DME, ILS, MLS INS
WADGPS LAAS GPS MAP
SURVEILLANCE
PRIMARY/SECONDARY SURVEILLANCE RADARS
AUTOMATIC DEPENDENT SURVEILLANCE (ADS) (SATELLITE BASED)
TCAS
BETTER TCAS
CONCLUSIONS
USE OF SATELLITES IN 'FREE FLIGHT' IS A MUST FOR CNS
ADS: AIRCRAFT AUTOMATICALLY TRANSMITS, VIA A DATA LINK, FOUR DIMENSIONAL POSITION DATA DERIVED FROM ON-BOARD NAVIGATION SYSTEM. SATELLITE BASED ADS MEANS USE OF SATELLITES FOR POSITION DETERMINATION & DATA LINKS.

Speaker profile

1. Ph.D in EEE discipline in 1980 from BITS, Pilani, India.
2. Taught graduate and under graduate students of Electrical and Electronics Engg (EEE) at BITS, Pilani from 1972-78.
3. Joined ISRO HQ in 1978. Currently, Programme Director, SATNAV and Deputy Director, INSAT Programme. As Programme Director, SATNAV, responsible for planning the Indian SATNAV Programme and interacting with user agencies/international groups. As Deputy Director, INSAT Programme responsible for future planning of the INSAT System.
4. Several papers in IEEE, US and IEE, UK journals.
5. Invited by Director General, European Space Agency (ESA) as an International Fellow at ESTEC, the Netherlands for 4 months to work on Global Navigation Satellite System (GNSS).
6. Member of the National Steering Committee (NSC) for satellite based CNS/ATM chaired by Secretary, Civil Aviation, Govt. of India.
7. Member from India to the International Committee on GNSS, Office of Outer Space Affairs, Vienna, UN
8. Country Point of Contact of Department of Transportation, US CGSIC
9. Member of the Indo-US Working Group on Civil space
10. Member of the PNT Federal Advisory Committee of US.
11. Chaired the second meeting of the International Committee on GNSS (ICG) held in Bangalore between Sept. 4 –7, 2007.

Image Exploitation System for Unmanned Aerial Vehicle

Dr. Jharna Majumdar, Professor,
Dept. of Computer Science,
East Point College of Engg. & Technology, Bangalore.

Image Exploitation, an innovative image utilization program, uses multi sensor, multi resolution and multi spectral imagery from Aerial or Ground based Reconnaissance Platform for the purpose of Extraction, Exploitation, Dissemination and Interpretation of Imagery. Major operational goal of image exploitation technology is to extract the vital intelligence from a glut of available imagery by filtering those which are most likely to produce valuable findings. Classical image/signal processing techniques cannot handle the complexities and the uncertainties involved in a real world scenario. Image Exploitation combines the classical methods with the technologies available in other fields such as Pattern Recognition, AI, Neural Network, Fuzzy Logic, Probabilistic Reasoning etc. and uses specialized hardware like DSP or embedded processor to finally deliver system of excellence as demanded by defense research.

The talk describes the development of a Ground based Image Exploitation System for Unmanned Aerial Vehicle developed at the Aeronautical Development Establishment (DRDO), Bangalore, India.
Two major components of the system are, a system named as GIES-Core, located at the Ground Control Station of UAV and a second system named as Imagery Intelligent Exploitation System (IMINT-ES), located at the Surveillance Center. The capabilities of these two systems and some of the key research areas, which form the basic backbone for their development, are covered in the talk.

The talk also highlights, in brief, some of the critical research areas in Image Processing/Computer Vision, required for the development of an Enhanced Vision Aircraft.

Design and Development of Enhanced Vision System for Flight Guidance Applications

- A continuing objective for the Aviation industry is to make flight safer by improving the display of information to the pilot
- Existing technology uses Head-Up Displays (HUD) in their cockpits to provide certain information
- The next step towards the technology advancement and extending the operational capabilities is to integrate HUD with Enhanced Vision Systems (EVS)
- Research is in progress all over the world for the development of Enhanced Vision System (EVS) for Aircraft. Much more research needs to be done to improve the results

An Enhanced Vision System (EVS) for Flight Guidance Applications

- Expands the **Operational Envelope** of the aircraft
- Enable the pilot **to be able to "see"** the environment in poor visibility condition and **navigate** successfully
- Help the pilot during **Landing and Taxiing** under adverse weather condition
- Has the ability for **obstacle detection and avoidance**
- Provide improved **Situational Awareness**
    - Automatic machine recognition of potential hazards of the pilot
    - Alerting the crew the system status
    - Automatic respond to certain situation and suggesting a revised flight plan

Steps for the Development of EVS……………..

- Identifying the technologies needed to develop EVS Systems
- Study of existing algorithms and the suitability of their use
- Development of advanced algorithms which are robust and efficient
- Analyzing the time criticality of the algorithms
- Identifying the appropriate hardware for those which needed real time implementation
- Integrating the system which would satisfy the requirement
- Testing and validation in the real life environment

Existing Systems are:

- Without EVS Capability
- Individual Systems having poor integration
- Information from a number of Devices are displayed with inconsistent display formats
- In a critical situation, pilot requests manually a new flight plan

Other Requirements……………..

- Presenting all required information in consistent form into one system and with one user interface
- Highlighting important information required in the present context by filtering only the necessary data

An effective Enhanced Vision System must operate over broad spectral range in order to offer the pilot an optimized scene that contains runway background, airport lighting and airport operations

The large dynamic range of intensities of these images need to be handled by separate imaging sensors

CCD Camera	**Visible Range**
Long Wave IR Camera	**8000 – 15000 Nanometer spectral band**
Short Wave IR Camera	**900 – 1680 Nanometer Spectral band**

One of the major objective of Enhanced Vision System (EVS) is :

- Real time acquisition of video from multiple cameras
- **Processing** to improve the quality of data

  → **Enhancement, Fiter(?), Registration and Fusion**

- Provide one Single Output as Display in real time **(12 to 25 frame per sec ?)**

■ Safe Landing and Taxiing in Poor Visibility Condition :

Mosaicing, terrain modeling, geo registration of mosaic with terrain for obstacle detection

Mounting of Cameras

- All cameras can be mounted on one base plate and placed forward looking underneath the aircraft
- Appropriate processing of video will provide better than human observed imagery particularly during poor visibility condition
- Achieving the level of image improvement required several stages of processing and selecting specialized hardware
- The hardware – software integrated system of IP needs to be tested on actual flight trials

Technologies that will be required to develop Enhanced Vision System (EVS)

- **Vision Data Processing** - handling of Grey Scale/Color images, Still images and Video)
- **Preprocessing**

  Noise reduction :

  filters / adaptive filters

  Enhancement :

  Enhancement / Adaptive Enhancement

- **Mid Level/High Level Image Processing**

  Image Registration :

  Feature Extraction, Matching, Handling perspectives, Affine Parameter Estimation

Technologies that will be required to develop Enhanced Vision System (EVS) (Contd…)

  Image Fusion :

- **Image Processing/Computer Vision**

  Video Processing

  Panoramic Mosaicing

  Video Geo Registration - Registration of Video on Terrain model

- **State-of-the-art Display**

  Synchronization of heterogeneous parameters, design and develop a Common display

- **Recording and Replay system**

  To **Record** Video and Meta data in synchronization to be used throughout the life cycle and **Play back** during the development and testing phase

Image Enhancement

- Image Enhancement is a very important preprocessing step in many Computer Vision application

- Researchers around the world have proposed various techniques to improve the visual perception in images captured in poor visibility conditions

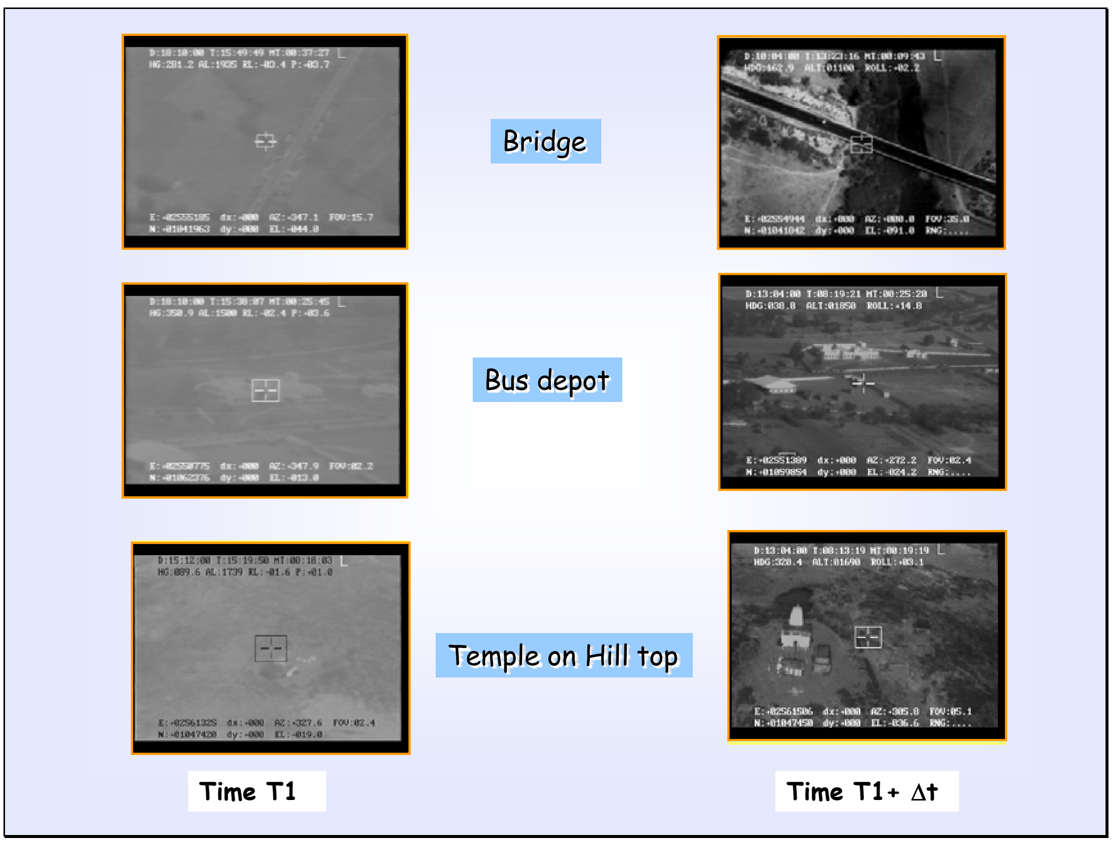
Need For Adaptive Enhancement

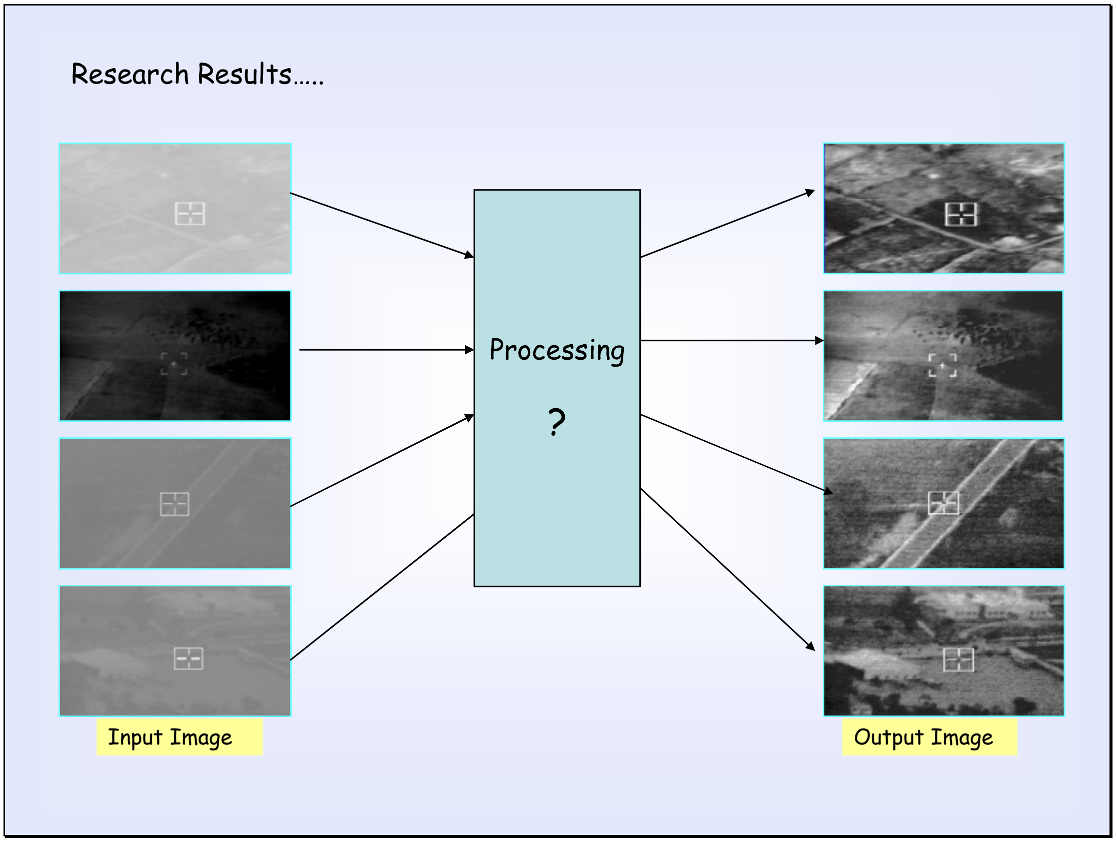
- Imagery acquired in unstructured and uncontrolled environment

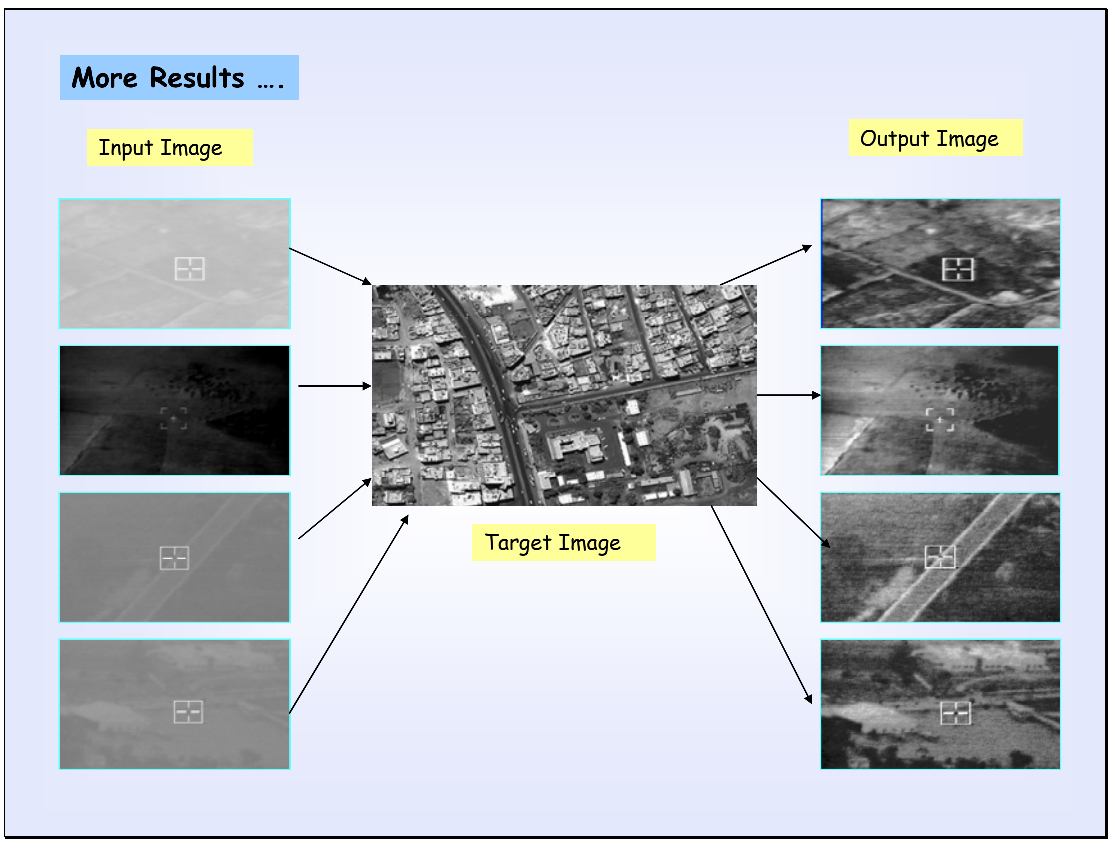
- Illumination characteristics of the environment and the surface characteristics of the terrain are not known

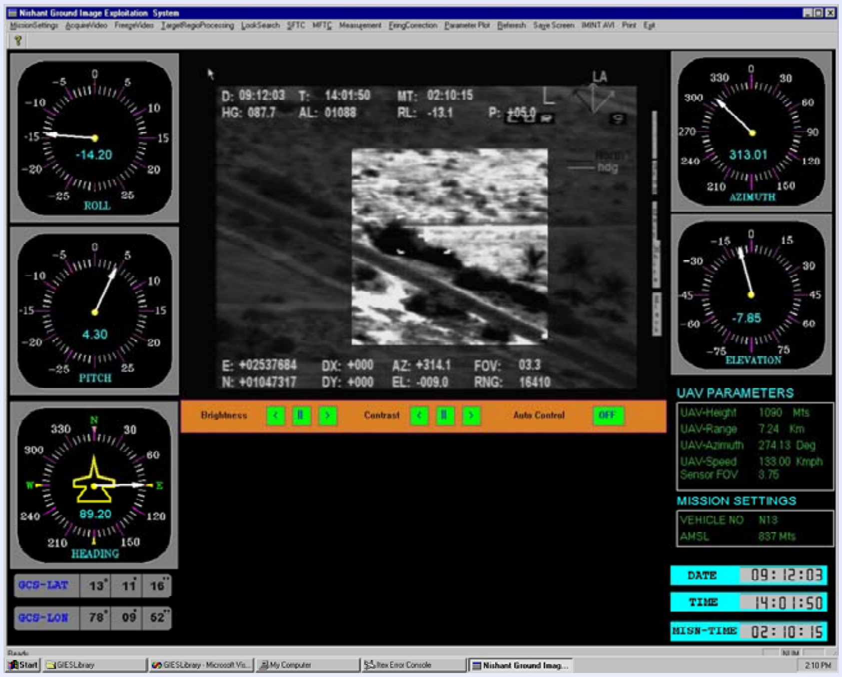
- Quality of the image is affected by fog, smoke and environmental noise

- No single algorithm can produce an acceptable output for improved human visualization




Research Results…..
Processing
?
Input Image
Output Image


More Results ….
Input Image
Output Image
Target Image



User Interface -Search for Target

Current research work on Adaptive Enhancement of Grey Scale Images

- Improved Histogram Specification
- Adaptive Histogram Equalization
- Adaptive unsharp masking
- Contrast-limited adaptive histogram equalization
- Adaptive neighborhood contrast enhancement

Enhancement of Color Images

Research in this area shows 'Non linear algorithm for enhancement of color images' provides good contrast, significant noise suppression and provide easy process to control luminance and contrast enhancement

This gave rise to the development of Retinex Algorithm - which provide good contrast, significant noise suppression and at the same time restoring color information

Development of Retinex Techniques

Algorithm 1: Single Scale Retinex (SSR) (the basic retinex algorithm which can either achieve color/lightness rendition or dynamic range compression but not both simultaneously)

Algorithm 2: Multi Scale Retinex (MSR) (overcomes the limitation of SSR and accomplish both color rendition and dynamic range compression effectively, but as an undesirable effect of making image colors greyer than what they should be)

Development of Retinex Techniques (Contd…)

Algorithm 3: Luminance Based Multi Scale Retinex (LB-MSR) (an improved version of MSR overcoming the greying effect)

Algorithm 4: Integrated Neighborhood Dependent Approach for Nonlinear Enhancement' (INDANE) (a new algorithm for color image enhancement)

Rendition: ability of a light source to accurately reproduce the color of various object faithfully

……Our research results

Input Image

Enhanced Image Using MSR

Enhanced Image Using LB-MSR

Enhanced Image Using INDANE

……Our research results

Input Image

Enhanced Image Using MSR

Enhanced Image Using LB-MSR

Enhanced Image Using INDANE

EVS Development Technology Demonstrator Project – NASA Langley Research Center

Dominant dark regions in the input image displays visible and clear view in the output image

Effectiveness of contrast enhancement process - car, railway track, pavements are distinctively visible

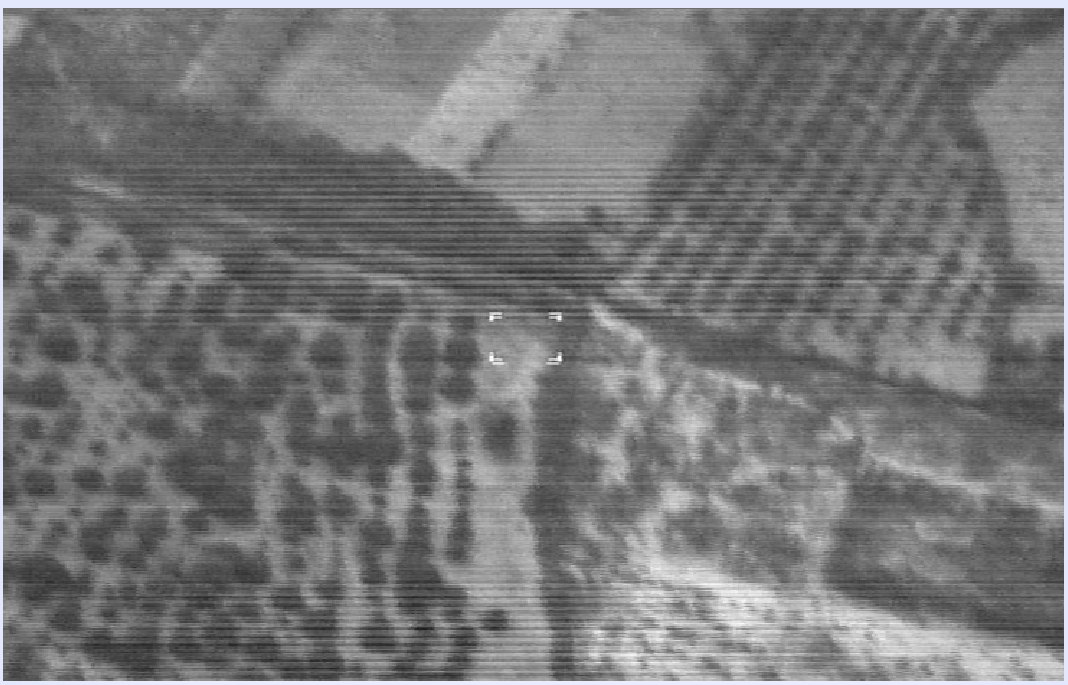
Enhancement using Non linear Retinex

Adaptive Filters

Algorithm 1: Adaptive Filter - Double Window Modified Trimmed Mean (DW-MTM) Filter

Algorithm 2: Noise Removal Filter -Alpha Trimmed Mean Filter

Algorithm 3: Noise Removal Filter - Contrast Harmonic Mean Filter



Input Image

Adaptive DW MTM Filter
K = 2 SD = 30 Window size (Median) = 3x3 Window size (Mean) =5x5

Image Fusion

Produce a single image from a set of input images. The fused image should have more complete information which is more useful for human or machine perception

- Availability of complementary information
- Improved performance to countermeasures it is hard to camouflage an object in all possible wave-bands
- Improved performance in adverse environmental conditions, smoke or fog cause bad visible contrast, rain cause low thermal contrast

> - Low Level (Pixel or Measurement Level) Fusion
> - Medium Level (Feature or Sensor Level) Fusion
> - High Level (Decision Level) Fusion
> - Temporal Level Fusion

……Our research results

Input Image 1

Input Image 2

Input Pair of Image

Pixel based Fusion of multi focus images

……Our research results

Visual Image

IR Image

Daubechies Wavelet Based Fusion of multi sensor images

……Our research results

Multi Sensor Image Data Fusion for Detection of Targets

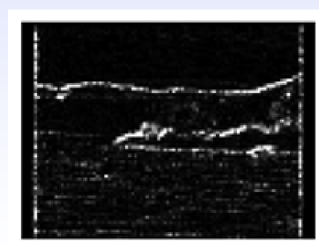
IR Image (a truck and a helicopter)

Visual Image (a truck, smoke, mountain in the background)

Haar Wavelet based fusion

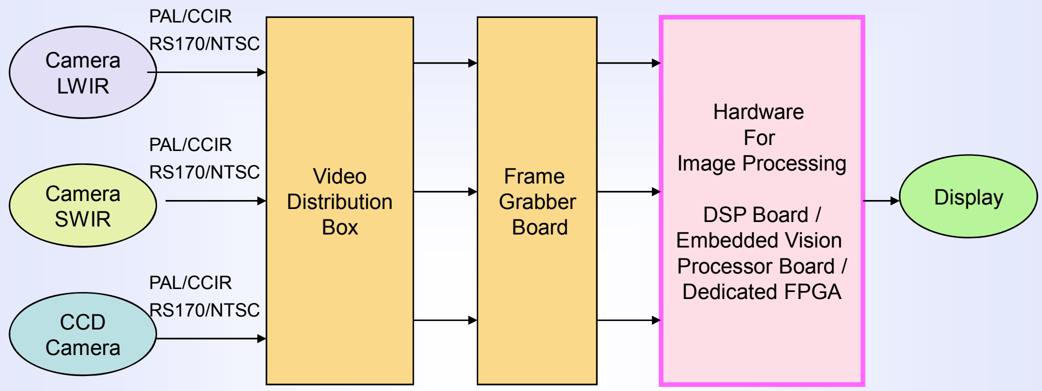
Feature level Fusion (Using texture features)

IR

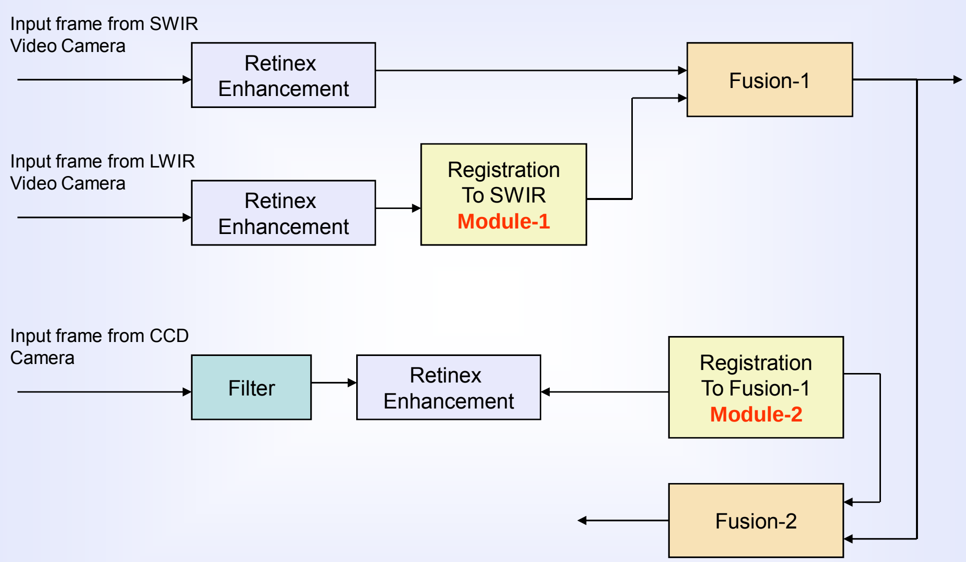


Visual

Sensor Level Fusion (using Linear/Non linear Discriminate analysis



IP Segment of the proposed EVS



Real time Image Processing for the proposed EVS

Research in EVS Technology - The **Advanced Technology Demonstrator Project** at NASA Langley Research Center. Prototype of EVS-2000 was demonstrated in Boeing 757-900 Aircraft

Input SWIR Image

Enhanced SWIR Image

Enhanced, Registered, Fused Image

Transformed LWIR Image

Enhanced LWIR Image

SWIR Image from night Flight

LWIR Image from night Flight

Enhanced, Registered, Fused Image

SWIR Image from day Flight

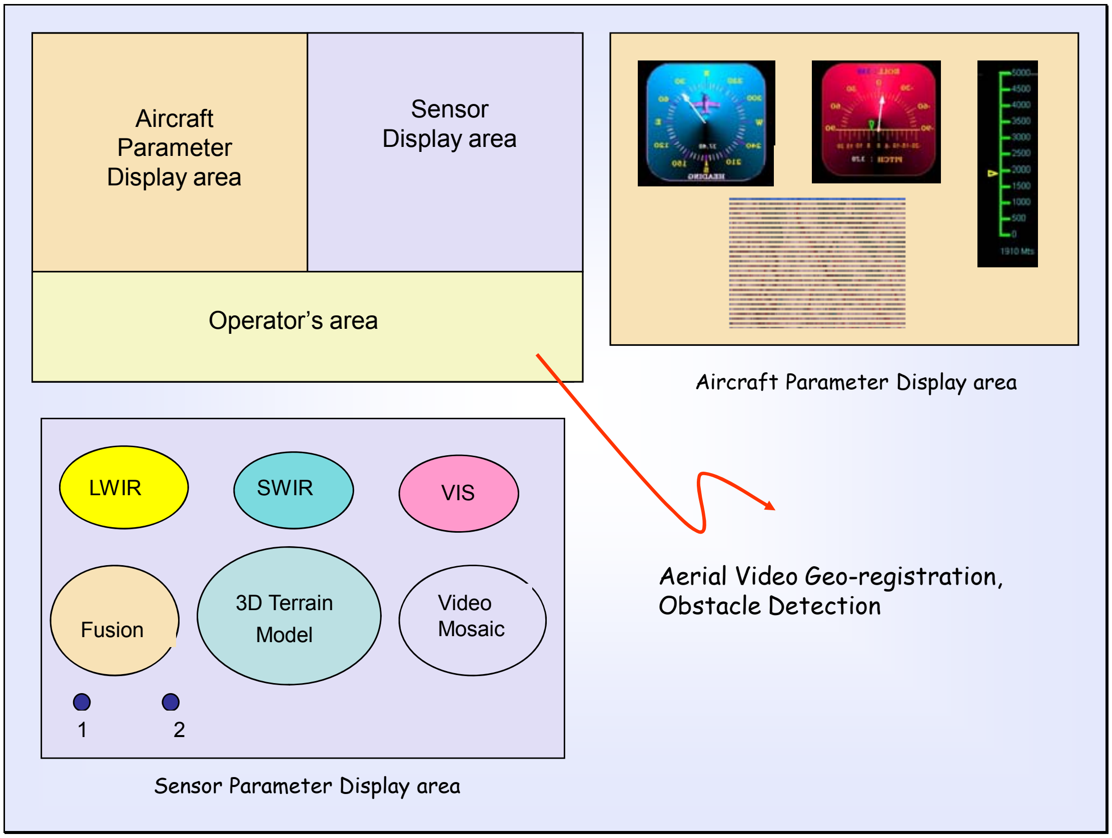
LWIR Image from day Flight

Enhanced, Registered, Fused Image

LWIR

SWIR

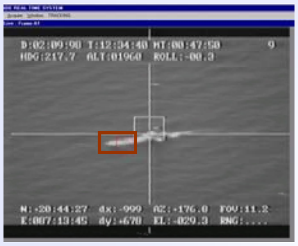
VISUAL



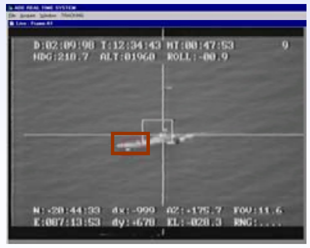
Some of other research work…………

Target Tracking

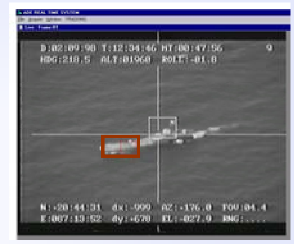
Tracking Examples with real images



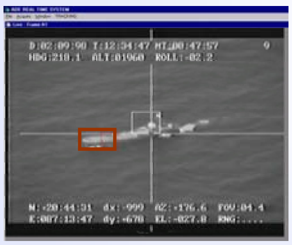
Frame 1



Frame 2



Frame 3

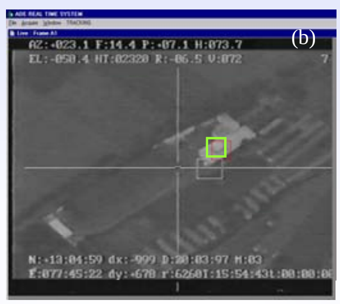


Frame 4

Frame 5

Tracking Examples with real images

Frame 1



Frame 2

Tracking

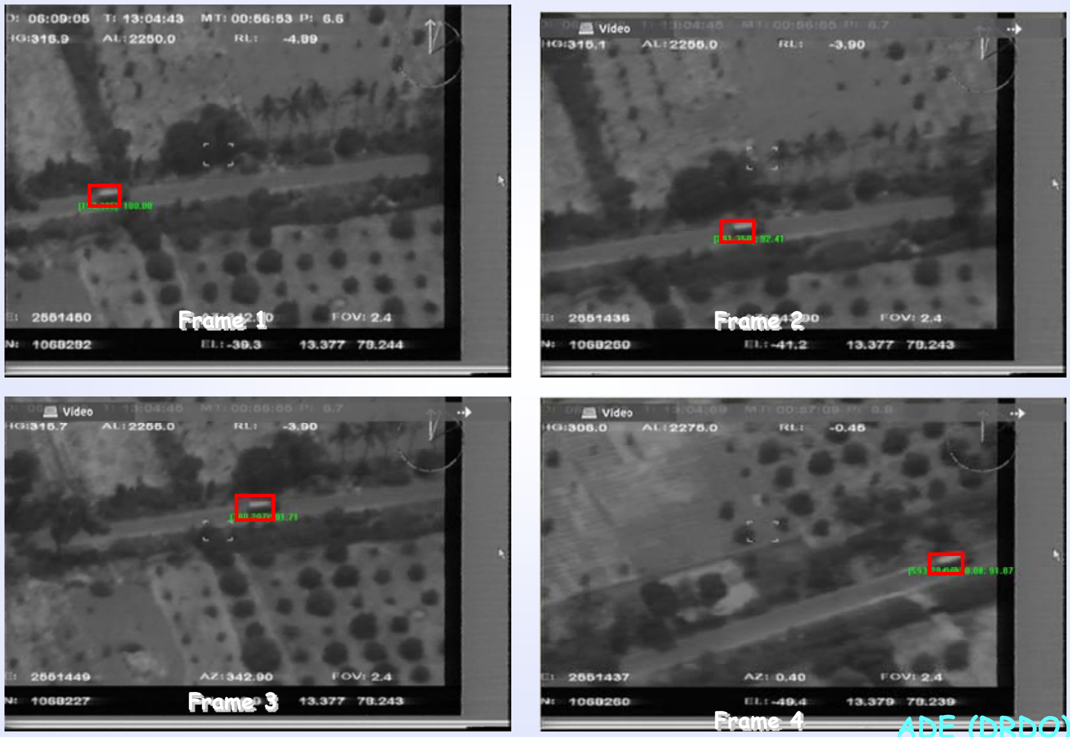
Frame 3

Frame 4

Frame 5

Frame 5

Single Target Tracking in near real time - Static objects, using Embedded Vision Processor

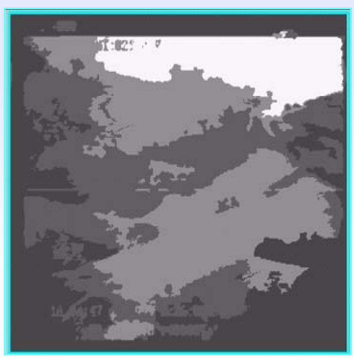


Multi Target Tracking in near real time - Static objects, using Embedded Vision Processor

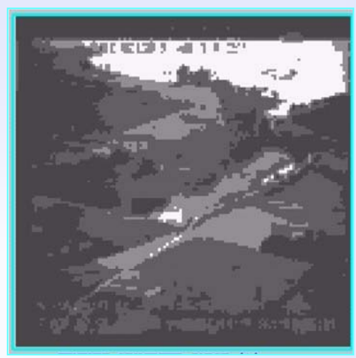
Segmentation and Terrain Classification

UAV Image

Input image - 1



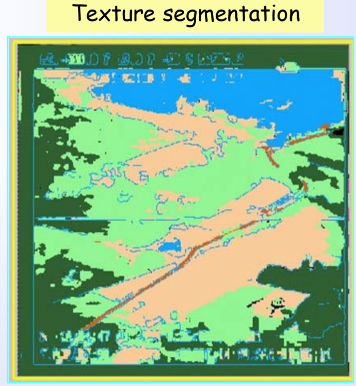
Intensity segmentation



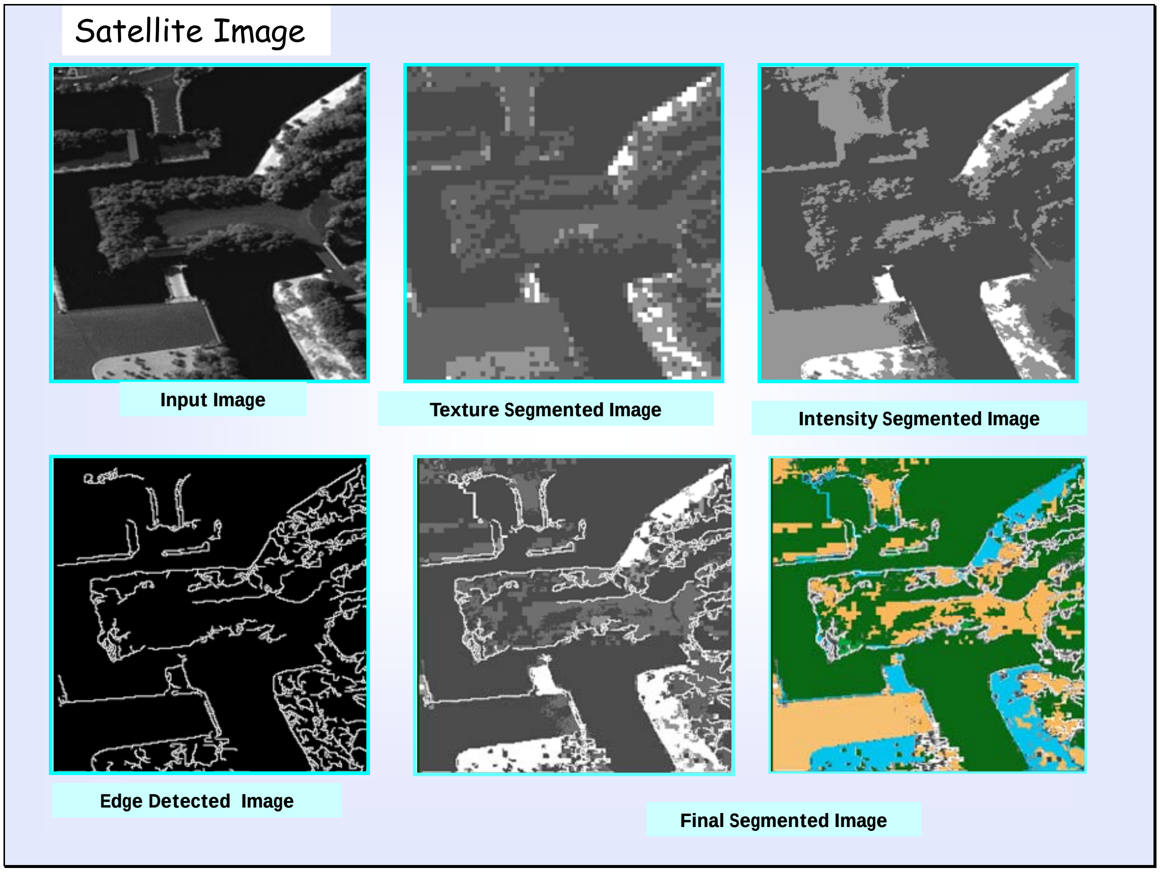
Texture segmentation

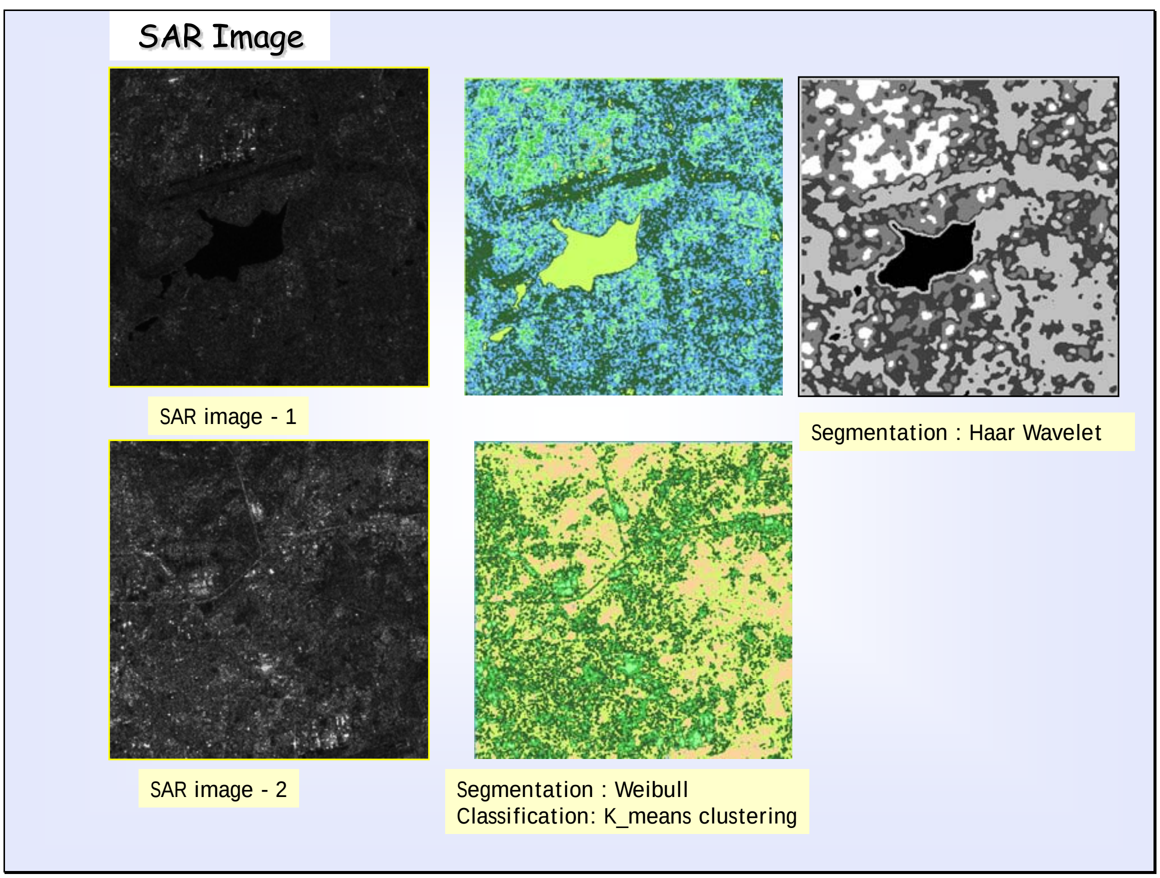
Edge detected image

Edge image superimposed on segmented image



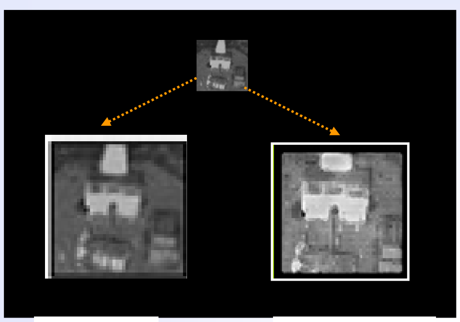
Classified image


Satellite Image
Input Image
Texture Segmented Image
Intensity Segmented Image
Edge Detected Image
Final Segmented Image

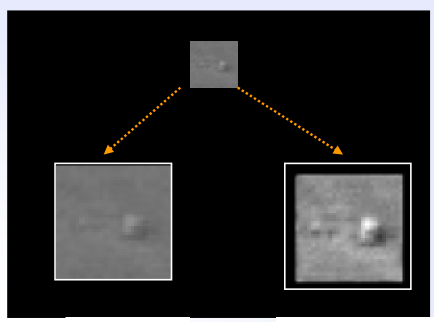

SAR Image
SAR image - 1
Segmentation : Haar Wavelet
SAR image - 2
Segmentation : Weibull
Classification: K_means clustering

High Resolution Reconstruction of Target Region

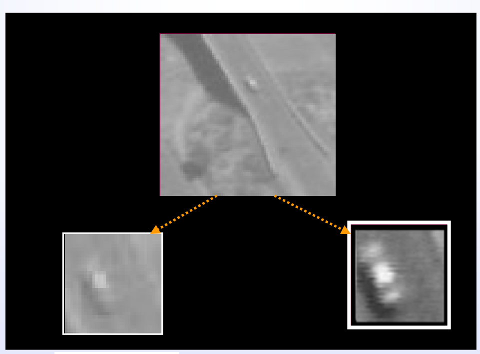
Results.....



Scaling Reconstruction

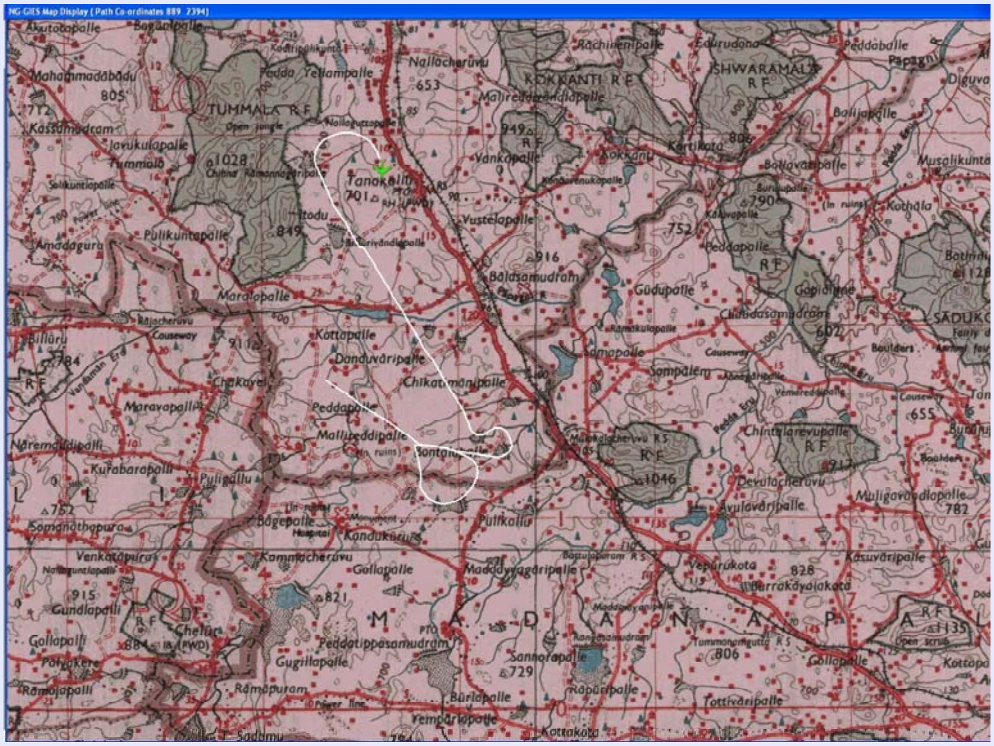


Scaling Reconstruction



Scaling Reconstruction

Thank You



[15] S. M. Pizer, J. B. Zimmerman, and E. Staab, “Adaptive grey level assignment in CT scan display,” Journ. Of Comp. Assist. Tomography, vol. 8, 1984, pp. 300-305.

[16] Z. Rahman, D. Jobson, and G. Woodell, “Multiscale retinex for color image enhancement,” Proceedings of the IEEE International Conference on Image Processing, 1996.

[17] L. Tao and V. K. Asari, “An Adaptive and Integrated Neighborhood Dependent Approach for Nonlinear Enhancement of Color Images,” SPIE Journal of Electronic Imaging, 2005

EVS System developed at NASA Langley Research Center

[5] D. J. Jobson, Z. Rahman, and G. A. Woodell, “Properties and performance of a center/surround retinex,” IEEE Trans. on Image Processing 6, pp. 451–462, March 1997.
[6] D. J. Jobson, Z. Rahman, and G. A. Woodell, “A multi-scale Retinex for bridging the gap between color images and the human observation of scenes,” IEEE Transactions on Image Processing: Special Issue on Color Processing 6, pp. 965–976, July 1997.
[7] G. D. Hines, Z. Rahman, D. J. Jobson, and G. A. Woodell, “Single-scale retinex using digital signal processors,” in Global Signal Processing Conference, September 2004.

Include the following materials at this point

1. Histogram Specification for adaptive enhancement for grey scale images
2. MSR, LB-MSR and …… for color images

EVS System developed at NASA Langley Research Center

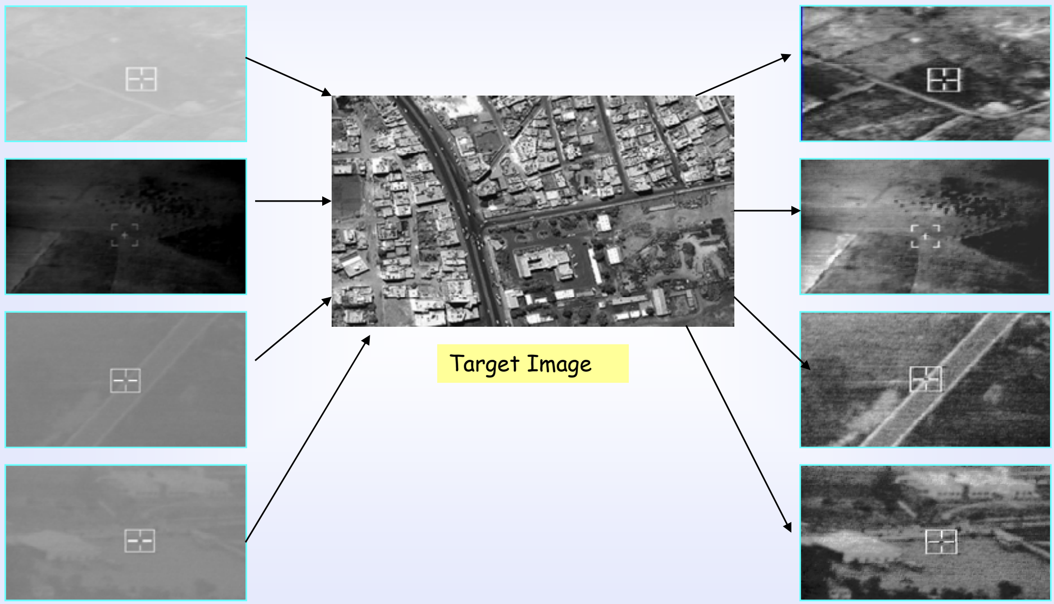
[5] D. J. Jobson, Z. Rahman, and G. A. Woodell, “Properties and performance of a center/surround retinex,” IEEE Trans. on Image Processing 6, pp. 451–462, March 1997.
[6] D. J. Jobson, Z. Rahman, and G. A. Woodell, “A multi-scale Retinex for bridging the gap between color images and the human observation of scenes,” IEEE Transactions on Image Processing: Special Issue on Color Processing 6, pp. 965–976, July 1997.
[7] G. D. Hines, Z. Rahman, D. J. Jobson, and G. A. Woodell, “Single-scale retinex using digital signal processors,” in Global Signal Processing Conference, September 2004.

	Long Wave Infra Red Cameras	Short Wave Infra Red Cameras
Typical Wavelength Range	7-12 μm	0.8-1.2 μm
	Commercial products based on LWIR technology are available since 2000	
Principle of Operation	Use radiation emitted by objects' temperature for detection based on high spectrum range	cover both visible and near infrared spectrums which as a result provide appearances of objects similar to visible spectrum
Advantages	High range; however, but not very useful since negative features are usually dominating	
Disadvantages	Unclear boundaries and road markings, not visible traffic signs since these signs adopt quickly to the surrounding environment	
	Unfamiliar appearances of persons and animals due to differences in temperature are also a disadvantage when LWIR cameras are used	

More Results ….

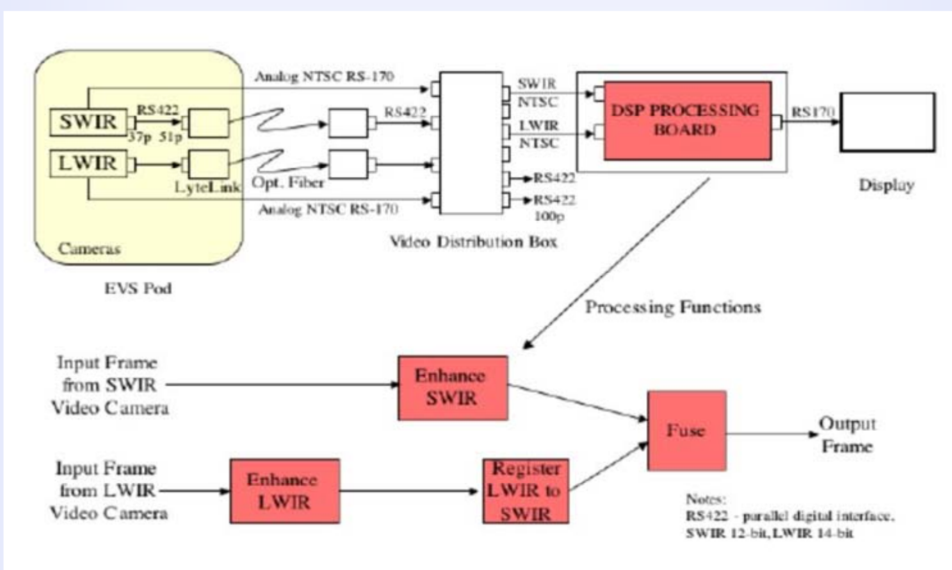
Input Image

Output Image



Target Image

The common feature for both LWIR and SWIR systems is that they all have monochrome video streams displaying in the Head-Up Display (HUD) somewhere in the car



[REF] G. D. Hines, Z. Rahman, D. J. Jobson, and G. A. Woodell, “Multi-sensor image registration for an enhanced vision system,” in Visual Information Processing XII, Proceedings of SPIE 5108, Z. Rahman, R. A.Schowengerdt, and S. E. Reichenbach, eds., April 2003.

The image processing functions performed on the video data streams are shown in the bottom of Figure 4.

The data streams (channels) from the cameras must be resized and enhanced, registered, and fused into a single image stream in real-time — 15-30 frames per second (fps)

Both camera video streams are enhanced using the Retinex to improve the information content of the imagery

The Retinex is a general-purpose image enhancement algorithm that simultaneously provides dynamic range compression, color constancy, and color and lightness rendition

Registration is required to remove the FOV dfferences in the cameras and to correct bore-sighting inaccuracies. The SWIR data is used as the baseline since it has the smallest FOV. The LWIR data is registered to the SWIR data by applying an affine transform to the LWIR imagery.3 A general representation of an affine transform is $[y_1, y_2, 1] = [x_1, x_2, 1]T$ where

$$T = \begin{bmatrix} a_{11} & a_{12} & 0 \\ a_{21} & a_{22} & 0 \\ a_{31} & a_{32} & 1 \end{bmatrix},$$

x_1 and x_2 reference the input coordinate system, y_1 and y_2 reference the output coordinate system, and a_{ij} are transform coefficients.4 The mapping functions are given as

$$y_1 = a_{11} x_1 + a_{21} x_2 + a_{31} \text{ and}$$
$$y_2 = a_{12} x_1 + a_{22} x_2 + a_{32}.$$

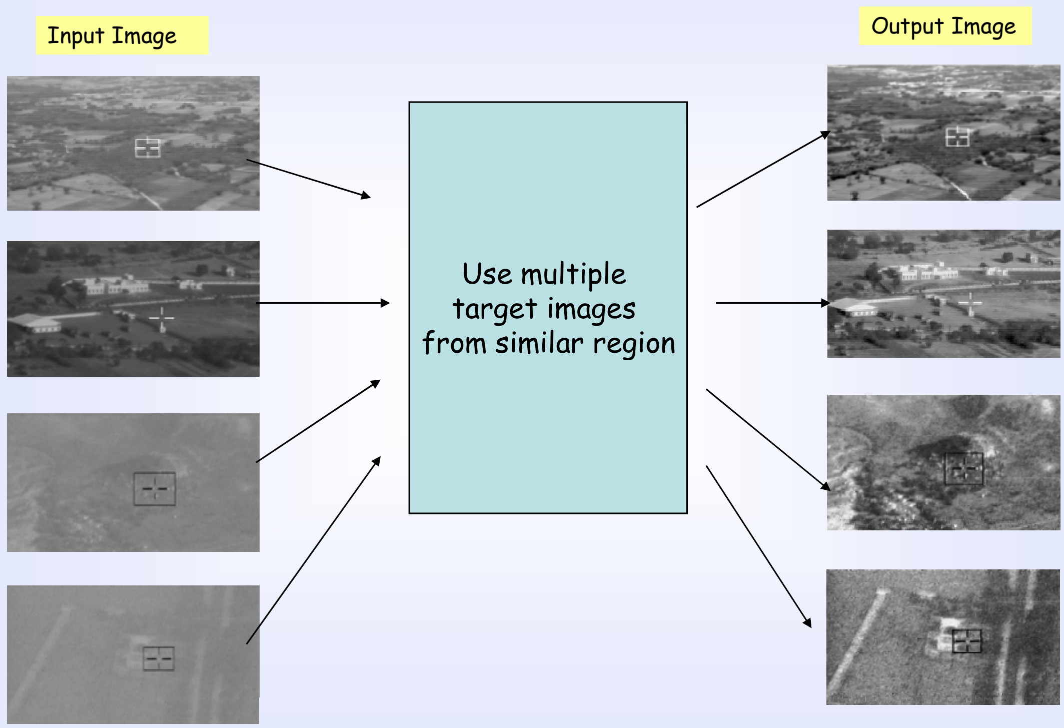
Prior to flight, a set of control points are selected based on corresponding features from sample images acquired at the same time from the cameras. The control points are analyzed using multiple linear regression to approximate the transform coeffcients a_{ij}, which is then applied to the LWIR image. The transformed LWIR image is then resampled using bilinear interpolation to align the LWIR image to the same grid as the SWIR image. The same transform coeffcients are used on all LWIR video frames during flight since both the FOV and the camera alignment should not change.

The enhanced and registered images are fused by effectively performing a weighted sum of the two processed outputs since a different Retinex is applied to each channel. Pixels are summed on an inter-frame basis. Other methods, such as interleaving frames or fields causes severe flicker. Lastly, the fused data stream is output as a standard composite NTSC signal into a display. The fused video stream contains more information than either individual camera output and also provides the additional benefit of producing a single output to observe.

Sequence of tasks for Registration and Fusion

- Resize the LWIR input image to 256 × 256 pixels
- Retinex the LWIR image
- Resize the SWIR input image to 256 × 256 pixels
- Retinex the SWIR image
- Register the enhanced LWIR image to the enhanced SWIR image
- Interpolate the LWIR image to the SWIR grid
- Fuse and output the final processed image

Current Work….



Speaker Profile

Dr. Jharna Majumdar received B.Tech (Hons.) in Electronics and Electrical Engineering and Post Graduate in Computer Technology from Indian Institute of Technology Kharagpur in 1969 and 1970 respectively. She received her PhD (Electrical Engineering) in 1980. She has about 36 years of research experience in India and abroad. She worked as a Research Scientist in the area of 'Robotics and Automation' at the Institute of Real Time Computer Systems and Robotics, Karlsruhe, Germany during 1983 to 1989. She served DRDO from 1990 to 2007 and retired as Scientist G and Head of Aerial Image Exploitation Division, Aeronautical Development Establishment (DRDO), Bangalore. Her research areas include Computer Vision, Pattern Recognition, AI, Parallel Processing and development of Image Exploitation System for Aerial and Ground Based reconnaissance platforms.

Dr. Majumdar published about 70 reviewed technical papers in national/international journals and conference proceedings. She received a large number of awards for her work from DRDO and other institutions. Some of her recent awards are: the award received from President, Stanford Research International (SRI International), California, USA for her research work during study leave in 2002, Performance Excellence Award in 2004, Dr V M Ghatage award in 2005, Dr. Suman Sharma Award in 2006 and Dr. Kalpana Chawla Memorial Lecture Award in 2007. Dr. Majumdar is a Fellow of Aeronautical Society of India and Life Member of the Computer Society of India.

She is currently associated as Adjunct Professor in the Dept of Computer Science, MIT Manipal and Professor, Dept of Computer Science, East Point College of Engineering, Bangalore.

e-mail: jharna.majumdar@gmail.com

Video Geo Registration

Anoop Prabhu, Kritikal Solutions, New Delhi

Traditional aerial guidance and assistance technologies had been limited to radar and navigation sensors like INS, GPS, etc. Advances in optical and wireless technologies have brought forward many sensors which provide valuable information for aerial guidance, enhanced visibility under adverse weather conditions, etc combined with emerging research in the area of intelligent image processing combined with a profusion of low cost high computing power platforms enable advanced visualization and data processing onboard aircrafts. Various signal processing and data visualization techniques can be employed to process the data in order to interpret the information present. This presentation focuses on image processing and computer vision techniques for image matching, data fusion, terrain visualization, geo-location for situation awareness, etc in order to extract information and display them in an easy to interpret fashion for pilot assistance.

Content based Image Retrieval

B.N.Chatterji, Prof (Retd), I I T Kharagpur

The recent invasion of digital multimedia in an entire range of everyday life has brought forth several active areas of research and Content Based Image Retrieval (CBIR) is one such area. In this talk the fundamentals of digital image processing will be discussed first. This will be followed by a brief review of the image enhancement techniques where (1) spatial linear/nonlinear smoothing of regions, (2) gray level rescaling, (3) edge enhancement using spatial domain linear/nonlinear high pass filter and (4) frequency domain filtering utilizing Fourier transform will be discussed. This will be followed by discussions on CBIR.

Retrieval of image data has traditionally been based on human insertion of some text describing the scene, which can then be used for searching by using the key board based searching methods. This is very time consuming and difficult for describing every color, texture, shape and object within the image. We know that image speaks thousands of words. So instead of manually annotated by text-based key words, images would be indexed by their own visual contents such as color, texture and shape. So researchers turned attention to content based image retrieval methods.

The lecture will introduce the need for content based image retrieval and will give a brief idea about historical developments. It will then provide a description of a typical content based image retrieval system. A few typical application of CBIR system will then be discussed. This will be followed by a brief discussion on visual features color, texture and shape etc. The color feature based CBIR will be discussed and the techniques like color indexing using distance method and reference color table method will be illustrated. The texture feature is very widely used for CBIR. The lecture will highlight the importance of wavelet transform (WT) based methods and will describe the WT based method in detail. The typical experiment using standard data base will be discussed.

Feature data base creation and retrieval will be discussed. A brief history of the shape based retrieval and the methods using (i) edge directions and (ii) invariant moments will be presented. The concept of dimensionality reduction and multidimensional indexing will be discussed briefly. Measure of retrieval efficiency and standard test bed will be introduced. The talk will conclude with discussions on the future research directions in CBIR.

Content Based Image Retrieval

by

Prof. B. N. Chatterji

Electronics and Electrical Communication Engineering Dept.
Indian Institute of Technology Kharagpur- 721 302
INDIA

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Contents

1. Introduction
2. System Architecture
3. Applications of CBIR.
4. Visual features.
5. Dimensionality Reduction and Multidimensional indexing.
6. Measure of Retrieval Efficiency and Standard Test bed.
7. Conclusion

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1. Introduction:

Why Image Retrieval ?

- Worldwide networking and rapid expansion of internet.
- The digital libraries and multimedia databases- consist of heterogeneous types of information.
- Data Superhighway- Everyday Giga Bytes of data is uploaded.
- Access to all of the information in the world is pointless without a means to search for it .
- We can not access or make use of the information unless it is organized so as to allow efficient browsing, searching and retrieval.

❖ Who ?

- Image retrieval lies at the crossroads of multiple disciplines such a Databases, Artificial Intelligence, Image Processing, Statistics, Computer Vision, High performance computing .
- All research communities study image retrieval from different angles.

❖ When?

- Research in this area started since 1970 .
- First conferences on Database techniques for Pictorial Applications was held in Florence in 1979.
- To solve the major problems in visual information retrieval, the US National Science Foundation (USNSF) organized a workshop in Redwood, California, in February 1992, to " identify major research areas for visual information management system that would be useful in industrial, educational entertainment, medical, scientific and environmental application" .
- Research area became active after 1990, because of WWW.

Earlier method :

- Text based- In 1970's this method was popular.
- Images are annotated with the text and then text- based search is used.
- DBMS Research community is involved in this area.

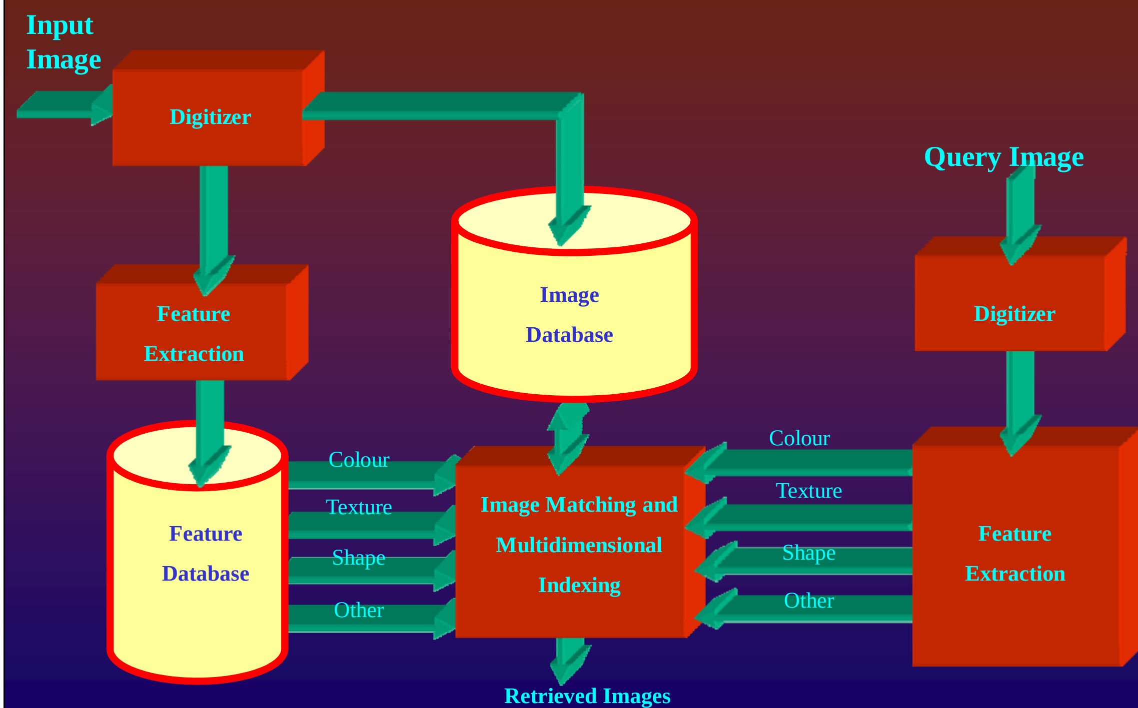
Disadvantages:

1. Difficult to describe every color, texture, shape, and object within the image.
2. Require more skilled labor and need very large, sophisticated keyword system. Also for same image content different people may perceive it differently.
3. Used keywords are context dependent → linguistic barrier → keywords will be ineffective for sharing image data globally.

How to overcome ?

- " An image speaks thousands of words".
- Images would be indexed by their own visual contents, such as color, texture and shape- CBIR.
- i.e. The retrieval of relevant images from an image database on the basis of automatically-derived image features
- Computer Vision Community is mainly involved in this area.
- Spoken document retrieval- Speech recognition Community.
- Challenge in Content Based Image Retrieval methods is developing methods, which will improve the retrieval accuracy and speed.

2. System Architecture:



3. Applications of CBIR

1. Crime prevention
2. Biomedicine (X-ray, Pathology, CT, MRI, ...)
3. Government (radar, aerial, trademark, ...)
4. Commercial (fashion catalog, journalism, advertising...)
5. Cultural (for exploring Museums, art galleries, ...)
6. Education and training
7. Architectural design
8. In Geographical information systems for finding where the local attractions are.
9. In remote sensing for example finding which satellite images contain tanks etc.

4. Visual Features

4.1 Color

4.1.1 Color Indexing using "Distance Method" and "Reference Color Table Method"

4.2 Texture

4.2.1 Texture image retrieval using Wavelet Transform

4.2.2 Related work on texture image retrieval

4.3 Shape

4.3.1 Shape based retrieval using Edge directions and Invariant Moments

4.3.2 Related work on image retrieval using shape feature

4.4 Other Features

4.1 Color

- Color does not only add beauty to objects but also give more information, which is used as powerful tool in CBIR.
- Goal - To retrieve all the images whose color compositions are similar to the color composition of query image.
- Typically the color composition is characterized by color histograms.
- In 1991 Swain and Ballard - color indexing using color histogram .
- Color histograms - way to represent the distribution of colors in images where each histogram bin represents a color in a suitable color space (RGB, L* a* b* etc.).
- A distance between query image histogram and a data image histogram can be used to define similarity match between the two distributions.

- The core idea is to compute

$$H(I, M) = \frac{\sum_{j=1}^{n} \min(Ij, Mj)}{\sum_{j=1}^{n} Mj}$$

- Where H (I, M) is the match value, and I and M are image (query image) and model (an image in the database) histogram respectively, each containing n bins.
- The match value is computed for every model histogram and the value is closer to unity if the model image is more similar
- It is obvious that a match value of unity is obtained for an image is the 3D color histogram h (x, y, z) and the similarity measure between features is given by the match value as shown in equation (1).

4.1.1 Color Indexing using "Distance Method" and "Reference Color Table Method":

- The histogram intersection technique does a detailed comparison by comparing every color bin of the 3-D color histogram of the two images.
- For many synthesized like trademark images, flags textile design patterns etc. detailed comparison is not required because:

1. There are large regions of uniform color $\longrightarrow$ 3-D histogram will have a few dominant peaks and the rest of the bins do not capture much color information of the images.
2. Also there is some noise introduced during the process of scanning color images. Hence fine comparison is not necessary and may even produce incorrect results.

- To overcome above problem in 1995 Mehtre et al. proposed two new color-matching methods the "Distance Method" and "Reference Color Table Method", for image retrieval.

❖ **Distance Method:**

- A coarse comparison of the color histograms of the query and model images.
- Find the mean value, μ, of the 1-D histograms of each of the three color components of the image as a feature.
- These components could be R, G, and B for the RGB representation .
- The feature vector $\bar{f}$ for characterizing an RGB image will be

$$\bar{f} = (\mu_R, \mu_G, \mu_B) \quad \text{---(2)}$$

- Compute Manhattan (city block) or Euclidean- for similarity measure using the following measures : $D_{qi}^{M} = \left| \bar{f}_q - \bar{f}_i \right| = \sum_{R,G,B} \left| \mu_q - \mu_i \right|$ ---(3)

$$D_{qi}^{E} = \sqrt{\left(\bar{f}_q - \bar{f}_i\right)^2} = \sqrt{\sum_{R,G,B} \left(\mu_q - \mu_i\right)^2} \quad \text{---(4)}$$

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❖ <u>**Where**</u>

- D_{qi}^{M} is the Manhattan distance between the query image and a database image.
- D_{qi}^{E} is the Euclidean distance.
- $\bar{f}q$ is the color feature vector of the query image.
- $\bar{f}_i$ is the color feature vector of the database image.

❖ The distance of an image from itself is zero.

❖ <u>Advantage:</u> The results show that both the new methods perform better than the existing histogram intersection methods.

❖ <u>Disadvantage :</u> A linear search is used, which can be very time consuming for large database.

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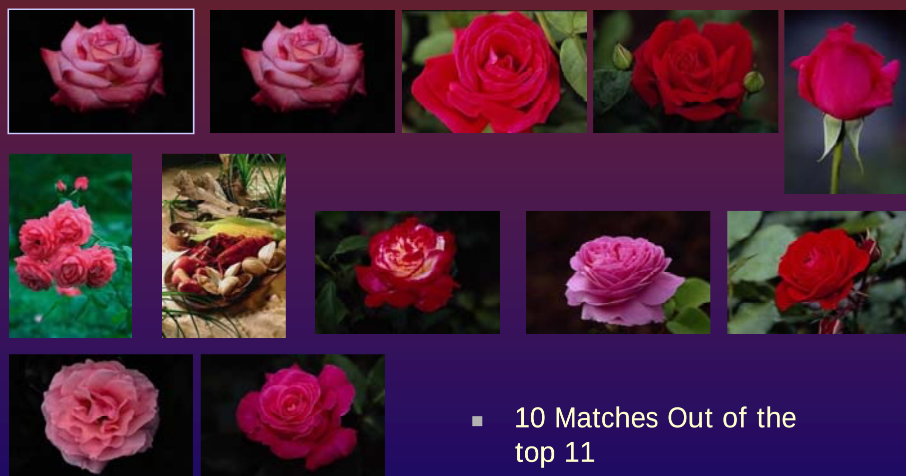
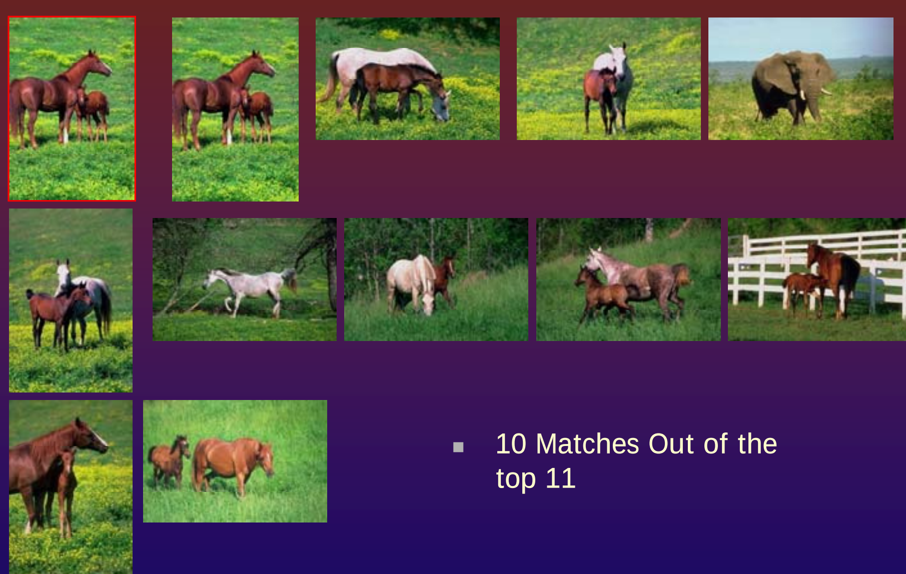
Example 1: Flower Query:



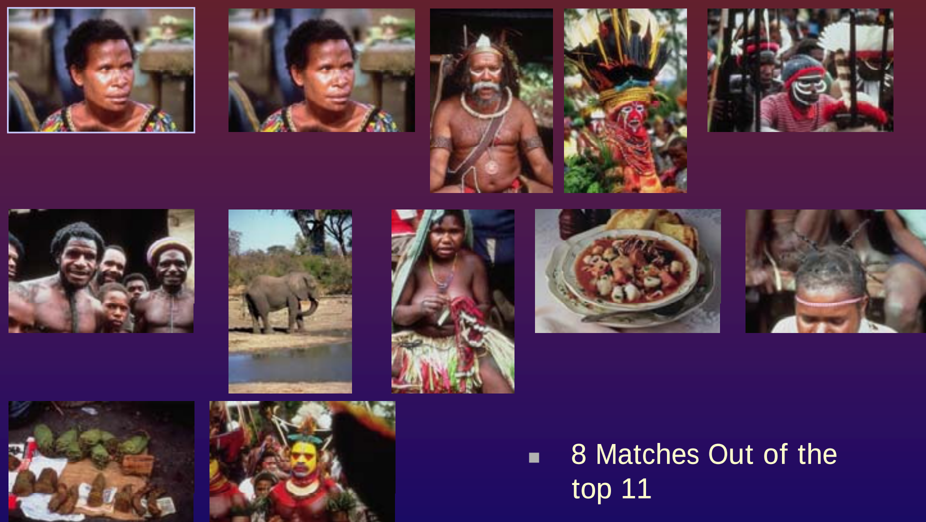
- 10 Matches Out of the top 11

Example 2: Horse Query:



- 10 Matches Out of the top 11

Example 3: African People Query:



- 8 Matches Out of the top 11

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3. Texture feature

- **Importance of texture feature is due to its presence in many real as well as synthetic data, e.g. clouds, trees, bricks, hair, fabric etc.**
- **Color alone cannot distinguish between tigers and cheetahs! – so texture is used in CBIR.**
- **Definition: " A region in an image has a constant texture if a set of local statistics or other local properties of the picture are constant, slowly varying, or approximately periodic".**
- **The main texture features currently used are derived from either Gabor wavelets or the conventional real discrete wavelets transform (DWT).**

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Disadvantages of Gabor Wavelet:

1. Gabor function do not form an orthogonal basis set → representation will not be compact → large space for storage.
2. Efficient algorithms do not exist for computing the forward and inverse transformation , which is essential in CBIR.
3. Computational time required for feature extraction is high, which limits retrieval speed.

Wavelet transform overcomes these problems.

❖ Texture Image retrieval using WT

- **Image Database used in experimentation:**
- Texture database consist of 116 different textures– Brodatz(108), USC database(7) and one artificial texture.
- Size of each texture is 512 X 512.
- Each of 512 X 512 images is divided in to 16 (128 X 128) nonoverlapping subimages, thus creating large database of 1856 images.

❖ Implementation of DWT using filters:

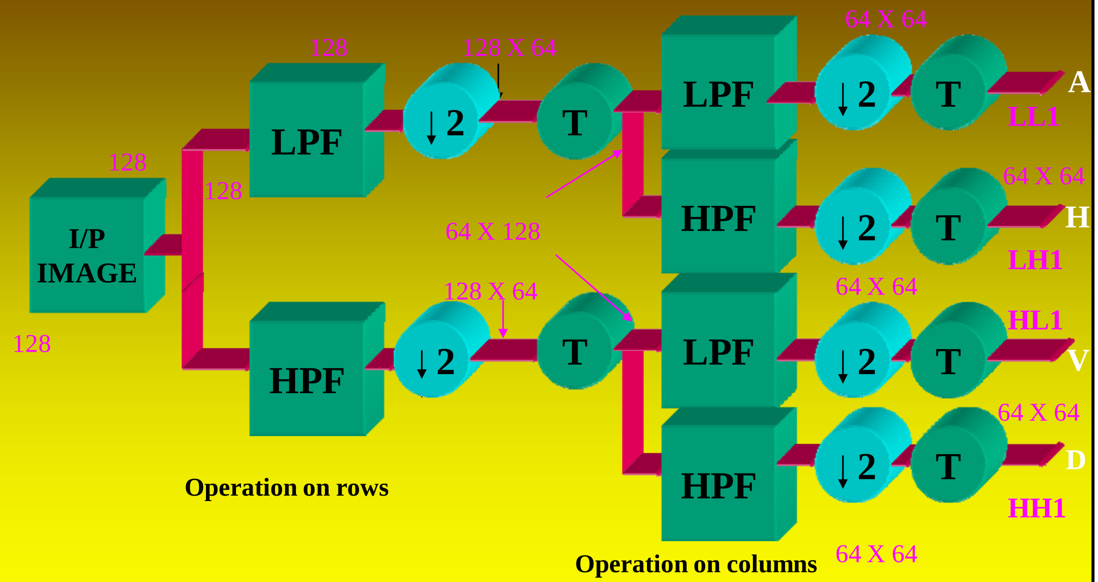

Fig2. First Level of WT implementation scheme.

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- **Feature Database Creation Phase:**

1. **Decompose each new database image with three level WT scheme, we will get 12 subband of three scale and four orientations.**

2. **For constructing feature vector measure mean, energy, standard deviation or possible combination on each subband and store that value in vector form.**

$$\text{Energy} = \frac{1}{M \times N}\sum_{i=1}^{M}\sum_{j=1}^{N}\left|X_{ij}\right| \qquad \text{Standard Deviation} = \left[\frac{1}{M \times N}\sum_{i=1}^{N}\sum_{j=1}^{M}\left(X_{ij}-\mu_{ij}\right)^2\right]^{\frac{1}{2}}$$

3. **Length of feature vector =(No. of subband X No. of feature measures in combination)**
4. **Repeat the procedure for all images, which you want to add in image database.**
5. **Store the resulting feature vector in matrix form, which will act as feature database.**

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•Image Retrieval Phase:

1. **Decompose Query Image with DWT scheme and construct its feature vector with 12 elements.**

2. **For image i in the database, pickup the values of one feature vector & denote by**

$$m_i = \left(m_{i,1}\ , m_{i,2}\ , ---------m_{i,j}\right)$$

3. **Calculate the distance function by**

$$Di = \|x - m_i\| = \sqrt{\sum_{j=0}^{n-1}\left(x_j - m_{i,j}\right)^2}$$

4. **Store the distance value and corresponding image index in distance vector.**

5. **Sort the distance vector and display the top similar images; say top 20.**

Query Image

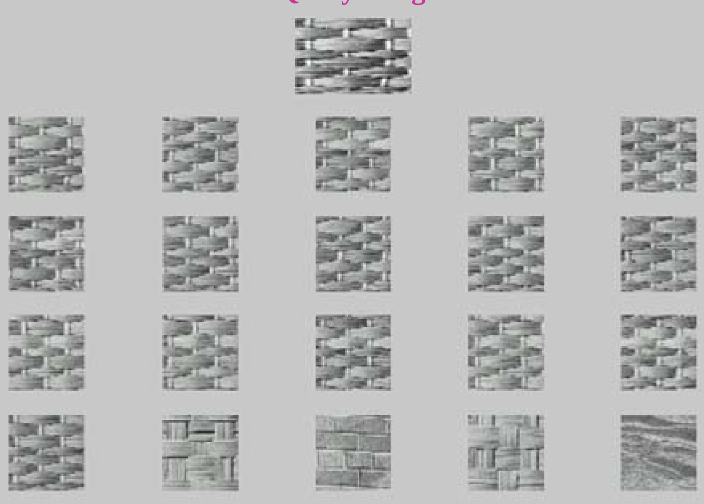

Fig.3. Retrieved top twenty images from the database of 1856 images.

❖ 4.3 Shape based retrieval

- Users are more interested in retrieval by shape than by color and texture.
- Goal is to retrieve the images from database which contain similar shape as the query image.
- Retrieval by shape - still most difficult aspects of content-based search .
- IBM's Query By Image Content, QBIC - relatively successful, but performs poorly when searching on shape. A similar behavior - in the new Alta Vista Photo Finder .
- In 1998 A.K.Jain and A. Vailaya used following two features for shape retrieval. First one is an edge angle, which is a histogram of the edge direction used to describe global shape information, and another one is invariant moments .

❖ 4.3.1 Shape based retrieval using Edge directions

- A histogram of the edge directions is used to represent the shape attribute.
- Extract the edge information contained in the database images off-line using the Canny edge operator (with $\sigma = 1$ and Guassian mask of size =9).
- Quantize the corresponding edge directions in to 72 bins of 5° each.
- A histogram of edge directions is invariant to translations in an image. i.e whatever may be the position of object.
- To achieve scale invariance , normalize the histograms with respect to the number of edge points in the image.
- A shift of the histogram bins during matching partially takes into account a rotation of the image.

- But, due to the quantization of the edge directions into bins, the effect of rotation is more than a simple shift in the bins. To reduce this effect of rotation, smooth the histograms as follows:

$$I_s[i] = \frac{\sum_{j=i-k}^{i+k} I[j]}{2k+1}$$

- Where I_s is the smoothed histogram, I the original histogram, K determines the degree of smoothness (k=1 is used).
- Once feature database is ready, process query image in same fashion.
- Compute the dissimilarity between two edge direction histograms using the Euclidean distance metric.
- Use retrieval procedure as explained

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❖ 4.3.1 Shape based retrieval using Invariant Moments

- Shape of an image is represented in terms of seven invariant moments.
- These features are invariant under rotation, scale, translation, and reflection of images and have been widely used in a number of applications due to their invariance properties.
- For 2-D image , $f(x, y)$,the central moment of the order (p+q) is given by:

$$\mu_{pq} = \sum\sum (x-\bar{x})^p (y-\bar{y})^q f(x, y)$$

- Seven moment invariants $(M_1 - M_7)$ based on the second and third order moments are given as follows:

$$M_1 = (\mu_{20} - \mu_{02}),$$

$$M_2 = (\mu_{20} - \mu_{02})^2 + 4\,\mu_{11}^2,$$

$$M_3 = (\mu_{30} - 3\mu_{12})^2\ (3\mu_{21} - \mu_{03})^2,$$

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$$M_4 = (\mu_{30} + \mu_{12})^2 + (3\mu_{21} + \mu_{03})^2,$$

$$M_5 = (\mu_{30} - 3\mu_{12})(\mu_{30} + \mu_{12})\left[(\mu_{30} + \mu_{12})^2 - 3(\mu_{21} + \mu_{03})^2\right] + (3\mu_{21} - \mu_{03}) \times (\mu_{21} + \mu_{03})\left[3(\mu_{30} + \mu_{12})^2 - (\mu_{21} + \mu_{03})^2\right]$$

$$M_6 = (\mu_{20} - \mu_{02})\left[(\mu_{30} + \mu_{12})^2 - (\mu_{21} + \mu_{03})^2\right] + 4\mu_{11}(\mu_{30} + \mu_{12})(\mu_{21} + \mu_{03}),$$

$$M_7 = (3\mu_{21} - \mu_{03})(\mu_{30} + \mu_{12})\left[(\mu_{30} + \mu_{12})^2 - 3(\mu_{21} + \mu_{03})^2\right] + (3\mu_{12} - \mu_{30})(\mu_{21} + \mu_{03})\left[3(\mu_{30} + \mu_{12})^2 - (\mu_{21} + \mu_{03})^2\right]$$

- $M_1 - M_6$ **are invariant under rotation and reflection,** M_7 **is invariant only in its absolute magnitude under a reflection.**
- **Scale invariance is achieved through the following transformation**

$$M_1' = \frac{M_1}{n},\ M_2' = \frac{M_2}{r^4},\ M_3' = \frac{M_3}{r^6},\ M_4' = \frac{M_4}{r^6},\ M_5' = \frac{M_5}{r^{12}},\ M_6' = \frac{M_6}{r^8},\ M_7' = \frac{M_7}{r^{12}}$$

- **Where** n **is the number of object points and r is the radius of gyration of the object given by :** $r = (\mu_{20} + \mu_{02})^{\frac{1}{2}}$
- **Once above feature database is ready, repeat same procedure for query image and then retrieval procedure is same as explained earlier.**
- **The edge direction-based matching takes into consideration the boundary of the objects whereas invariant moments are defined over an entire object region.**

❖ Other methods of image retrieval using shape features:

- **Global object features such as area, circularity, eccentricity, compactness, major axis orientation, Euler number, coactivity tree, shape numbers, and algebraic moments can all be used for shape description.**
- **In Modal matching rather than working with the area of an object, the boundary can be used . Samples of boundary can be described with Fourier descriptors, the coefficients of the DFT.**
- **Scale space approach is also used.**

❖ Dimensionality Reduction and Multidimensional Indexing

- Goal is to make the CBIR truly scalable to large size image database.
- Contribution of three measure Research Communities - Computational geometry, Database management and Pattern Recognition.
- Earlier methods were : Linear Searching, quad tree and k-d tree: performance was far from satisfactory.
- R and R* trees are used, but performance degenerates drastically with increase in dimensionality of feature space.
- To overcome above problems- Dimensionality reduction (DR) techniques used.
- In DR high dimensional feature vectors are mapped to a lower dimension.
- Karhunen- Loeve Transform (KLT) and column wise clustering is used for DR.

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• Disadvantages of DR

i. These techniques work well only when data is strongly correlated i.e. few independent dimensions (*I*) within high dimensional data space. If dimension is reduced below *I* then performance degrades.

ii. Not suitable in dynamic database envoirments because the transforms would have to be recomputed to cope with insert or deletes to the database.

- Charikar et .al. proposed an incremental clustering technique for dynamic information retrieval which has dynamic structure and high dimensional data handling capability.
- Guang-Ho Cha used HG- tree, which avoids most of all above problem

❖ Advantages of HG – tree:

i. Completely dynamic – i.e. it supports arbitrary insertions & deletions of the object without any loss of performance.

ii. No dimensionality problem because it represents each directory region covered by data set by using only two Hilbert values.

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❖ 6. Measure of Retrieval Efficiency and Standard Testbed:

- **Measure of Retrieval Efficiency:**
- **Any technique is pushed forward by its domain's evaluation criterion.**
- **SNR - in data compression, and recalls - in text-based information retrieval**
- **Good metrics will lead the technique in correct direction while bad ones may mislead the search effort .**
- **Currently, some image retrieval systems uses following measures:**

i. **the "cost/time" to find the right images.**

ii. **precision and recall, terms borrowed from text-based retrieval.**

- **Above measures of the system's performance are far from satisfactory .**
- **One major reason causing the difficulty of defining a good evaluation criterion is perception subjectivity of image content.**
- **But still, we need to find a way of evaluating the system performance to guide the research effort in correct direction.**

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Retrieval Efficiency:

Retrieval Accuracy $= \dfrac{\text{No. of similar images retrieved}}{\text{Total No. of images of that class in database}} \times 100\ \%$

$$\text{Precision}(N) = \frac{Rn}{N} \qquad \text{Recall}(N) = \frac{Rn}{M}$$

Where: N is number of retrievals
Rn is number of relevant matches among retrievals.
M is the total number of relevant matches in the database

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- **Standard Testbed**
  - **Important task -- To establish a well-balanced large- scale testbed**
  - **For image compression-- Lena image, (which has good balance in various textures).**
  - **For video compression-- the MPEG community developed well-balanced test video sequences.**
  - **For text-based information retrieval -- a standard large-scale testbed also exists.**
  - **For the image retrieval testbed-- the MPEG-7 community has recently started to collect test data.**
  - **For a testbed to be successful-- it has to be large in scale to test the scalability (for multidimensional indexing) to be balanced in image content to test image feature effectiveness and overall system performance.**

Lessons Learned

- Recent efforts are focused on indexing a few specific visual dimensions of the images, such as color, texture, shape, motion and spatial information. However without integrating these visual dimensions, the current content-based techniques have limited capacity to satisfactorily retrieve images.
- Color, texture, and shape features are not exploited enough
- Difficult to define semantic features
- Global features do not work well
- Single features do not work well alone

❖ Future Research Direction

Urgent need:

1. Try to reduce a significant gap between the ability of computers to analyze images and videos at the feature level (colors, textures, shapes) compared to the inability at the semantic-level (objects, scenes, people, etc.) .
2. Find new ways of improving retrieval efficiency since in multidimensional indexing there is loss of efficiency as number of dimension increases.
3. Exploit relevance feedback and Memory learning algorithm to improve retrieval efficiency.
4. Fuzzy logic in CBIR is not exploited enough.
5. Integrate visual features to improve efficiency of CBIR.
6. Find reliable and widely accepted ways of measuring. So correct judgment of effectiveness of new technique, will lead the advancement in this field.

Thank You…

Speaker Profile

B.N.Chatterji (date of birth 10 Nov.1942) obtained B.Tech Hons (1965) & PhD(1970) from IIT Kharagpur in Electronics & Electrical Communication Engineering. He did Post Doctoral work in Image Processing & Pattern Recognition from University of Erlangen Germany during 1972-73. Worked with Telerad Pvt. Ltd. Bombay (1965), CEERI (!966) & faculty at IIT Kharagpur from Jan 1967 till June2005. He was Professor (1980-2005), Head of the Dept.(1987-91), Dean Academic Affairs (1994-97) & Member Board of Governers of IIT Kharagpur (1998-2000). He is Fellow/Member of 10 Professional Societies, Coordinated 30 Short Term Courses, Chairman of 10 National/International Conferences & Chief Investigator of 25 Sponsored Projects. He has worked in Pattern Recognition, Image Processing, Computer Vision, Parallel Processing, Controls & Signal Processing. He has published more than 250 papers & four books. He has supervised 37 Scholars for PhD degree. He is the recipient of 10 National Awards.

A Flight Test Perspective on Display Concepts for Synthetic Vision

Sqn. Ldr. J Sreeram, ASTE, Bangalore

Enhanced vision refers to sensor-based information about terrain and man-made features when visibility is obscured. Synthetic vision is an artificial, computer-generated view based on a detailed terrain database. Combining the two can either be done via "fusion"--creating one image by blending sensor and database elements--or "integration," which overlays sensor and terrain data. The latter provides the flight crew with a synthetic view of the environment, regardless of the weather or time of day.

Enhanced and Synthetic Vision (ESV) systems aid in reducing risks by enhancing pilot situational awareness under adverse weather conditions. With ESV on board, a pilot is expected to make pseudo (virtual) VMC approach and landings in near zero visibility in hostile terrain with no terrestrial back up, or fly close to the ground in varying terrain either at night or in fog. Therefore such systems are expected to have a very high degree of reliability and redundancy. In addition, the display of information needs to be accurate, unambiguous and user friendly.

This paper lays out a progressive road map towards development and employment of an ESV System in our country from a flight test perspective. The capability to superimpose a synthetic runway (generated by the onboard navigation system) over the actual runway already exists in the DARIN Jaguar. Successive steps would involve the use of navigational information to determine aircraft position in relation to an existing terrain database. This would enable the generation of a synthetic vision display for the pilot. Thereafter onboard sensors like FLIR, EO or Radar would be employed to validate and refine positional information and the synthetic display and thus co-relate “what we see” with “what we should be seeing”. Each stage of integration and advancement would involve flight testing under various flight conditions to check system for robustness, reliability and display effectiveness.

DISPLAY CONCEPTS FOR ENHANCED AND SYNTHETIC VISION

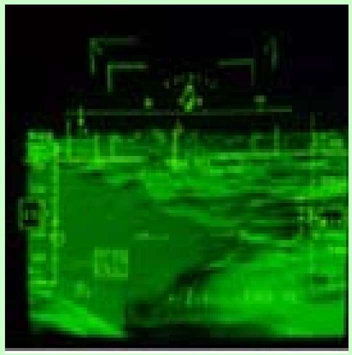
A FLIGHT TEST PERSPECTIVE

INTRODUCTION

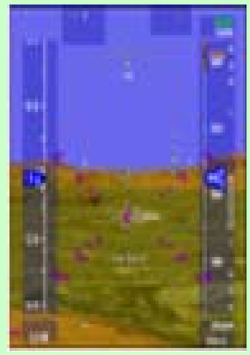
OVER 30 % OF ALL FATAL ACCIDENTS IN COMMERCIAL AVIATION - CFIT
CAUSES - REDUCED VISBILITY AND REDUCED SITUATIONAL AWARENESS

INTRODUCTION

SYNTHETIC VISION SYSTEM CONCEPT



HUD



MFD/PFD

INTRODUCTION

- **INTRODUCTION**
- **ENHANCED VISION OR SYNTHETIC VISION**
- **REQUIREMENTS FOR DEVELOPING AN ESV SYSTEM**
- **DISPLAY CONCEPTS**
- **THE INDIAN ROADMAP (LESSONS WE SHOULD CARRY)**
- **CONCLUSION**
- **QUESTIONS**

ENHANCED VISION

OR

SYNTHETIC VISION ?

ASTE

ENHANCED OR SYNTHETIC VISION

ASTE

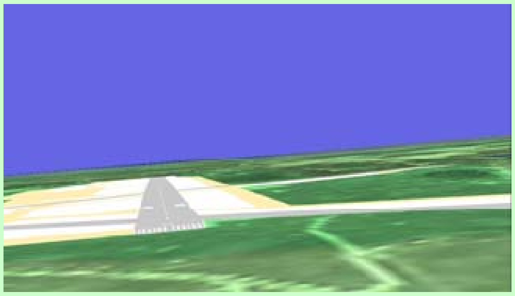
SYNTHETIC VISION

- INDEPENDENT OF WEATHER
- FIELD OF REGARD AS LARGE AS DATABASE
- BETTER CLARITY
- DERIVED VIEW. REQUIRES HIGH DEGREE OF DATA INTEGRITY MONITORING ESPECIALLY DURING CRITICAL PHASES OF FLIGHT

ENHANCED VISION

- WEATHER DEPENDENT
- LIMITED FIELD OF REGARD
- ADDITIONAL TRG REQD TO INTERPRET OBJECTS
- DIRECT VIEW. HIGH DEGREE OF CONFIDENCE. CAN BE USED IN CONJUNCTION WITH SVS FOR INTEGRITY MONITORING

ENHANCED OR SYNTHETIC VISION

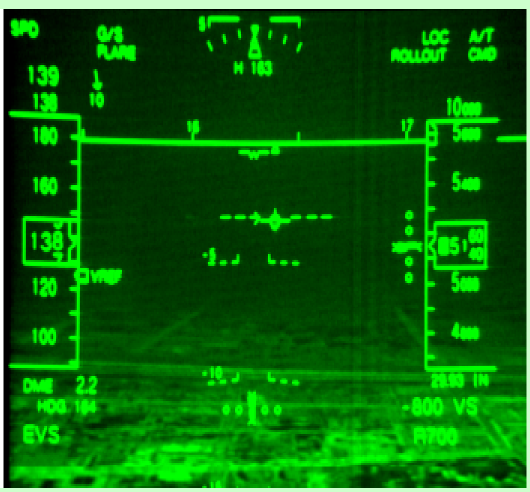


SYNTHETIC VISION

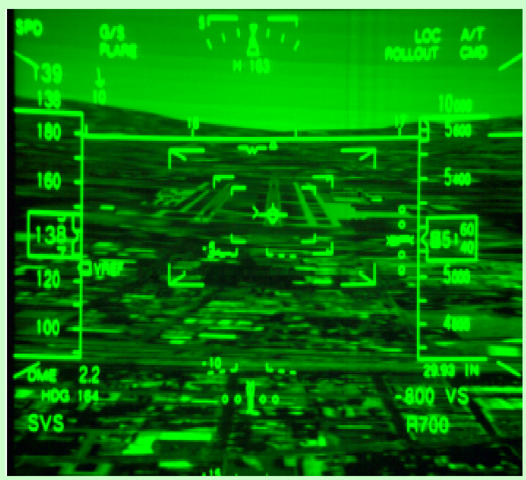
ENHANCED VISION

ENHANCED AND SYNTHETIC VISION !

A FUSION CONCEPT



BASELINE - FLIR ONLY



FUSED IMAGE

REQUIREMENTS FOR DEVELOPING AN ESV SYSTEM

- TERRAIN DATABASE
- PRECISE NAVIGATION DATA
- ENHANCED VISION SENSORS
- DATABASE INTEGRITY MONITORING
- DISPLAYS AND GUIDANCE SYMBOLOGY
- RETROFIT APPROACH

DISPLAY CONCEPTS

DISPLAY SIZE

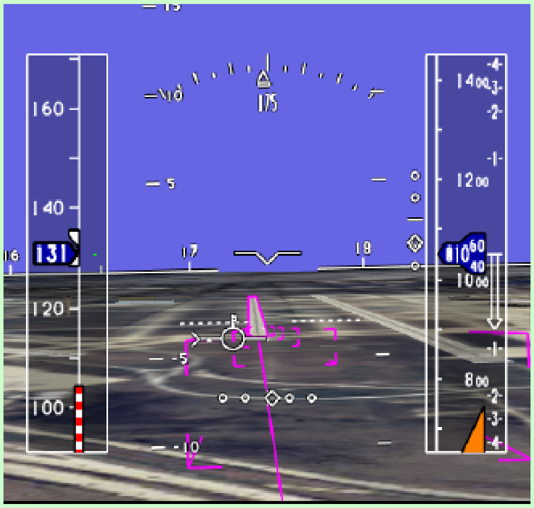
RESULTS

- LARGER DISPLAYS PREFFERED
- MULTIPLE FIELDS OF VIEW RECOMMENDED

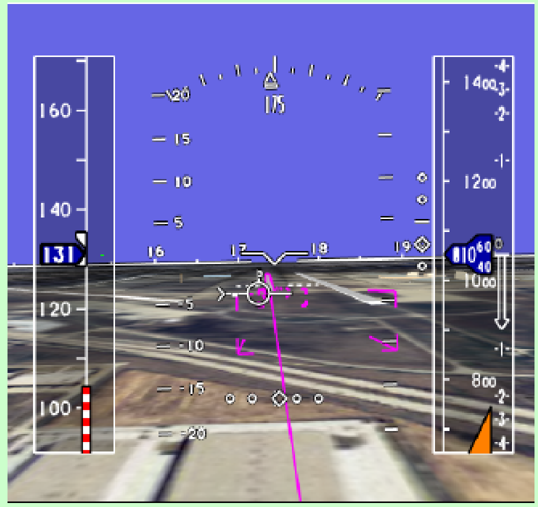
  50 DEG FOR NON FINAL APP MANEUVER SEGMENTS
  40 DEG FOR EARLY FINAL APP SEGMENTS
  30 DEG FOR LATE FINAL APP SEGMENTS

- HUD PREFERRED OVER PFD
- THOUGH HUD AND LARGER DIPLAYS LED TO BETTER PILOT PERFORMANCE, THE DIFFERENCE WAS NOT STATISTICALLY SIGNIFICANT

FIELD OF VIEW

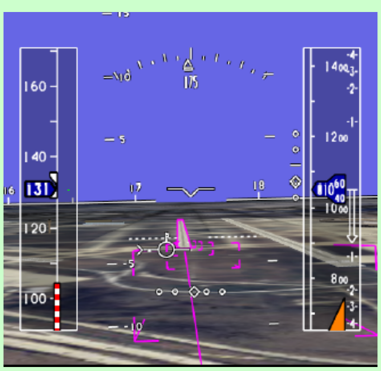


SIZE D 30 DEG FOV



SIZE D 60 DEG FOV

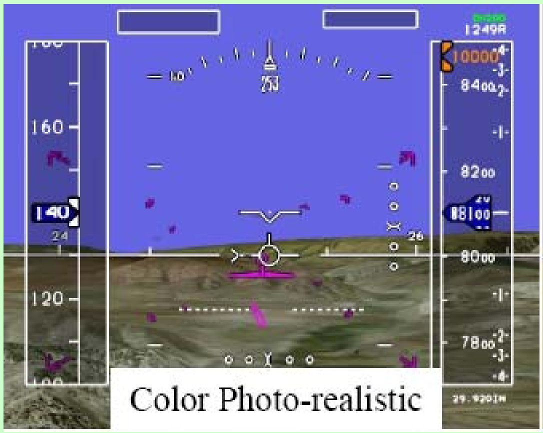
HUD VS PFD

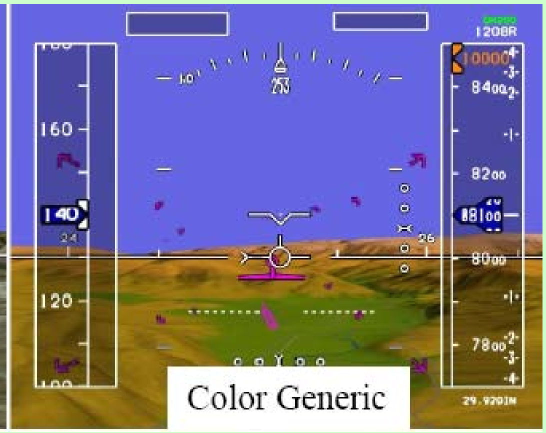


SIZE D

HUD

TERRAIN TEXTURING CONCEPTS





TERRAIN TEXTURING CONCEPTS

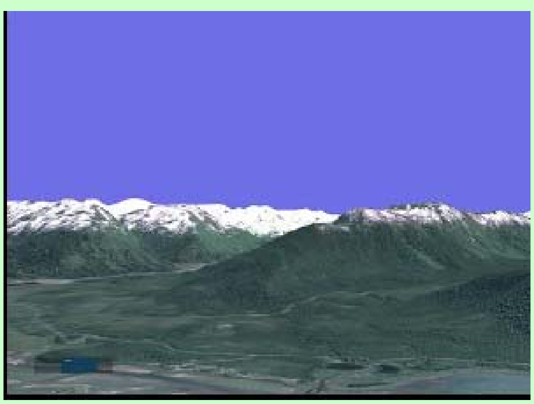
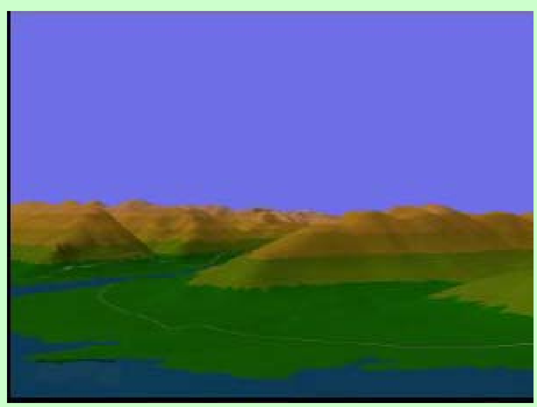


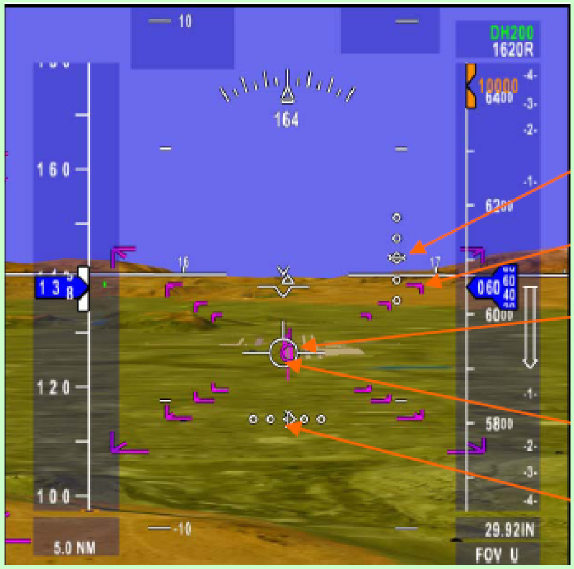
PHOTO REALISTIC



GENERIC

GUIDANCE SYMBOLOGY CONCEPTS

ADVANCE PATHWAY GUIDANCE



VERTICAL DEVIATION

CROW'S FEET

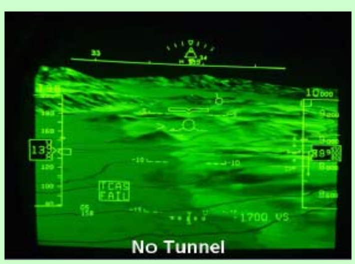
FLIGHT PATH MARKER

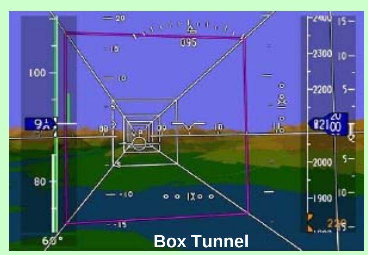
TADPOLE

HORIZONTAL DEVIATION

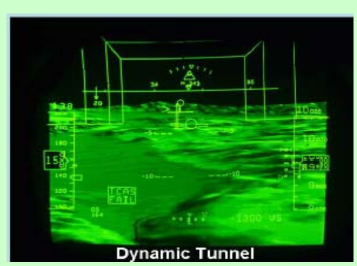
GUIDANCE SYMBOLOGY CONCEPTS

TUNNEL CONCEPTS


No Tunnel

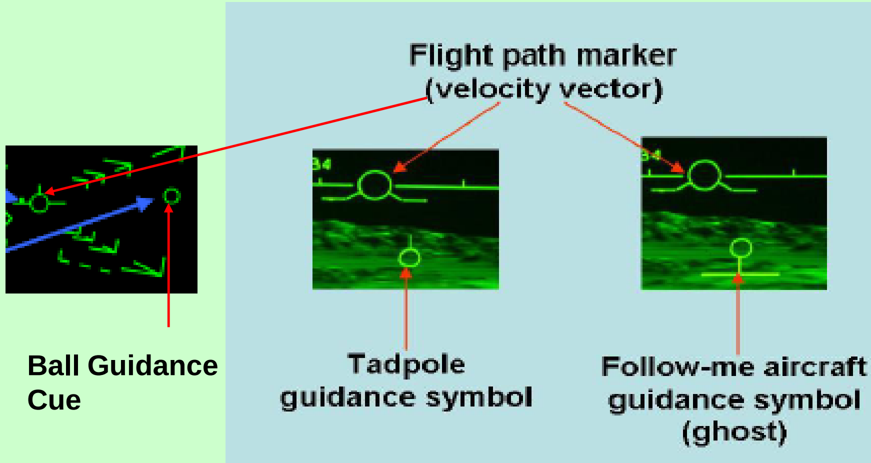

Box Tunnel


Minimal Tunnel


Dynamic Tunnel

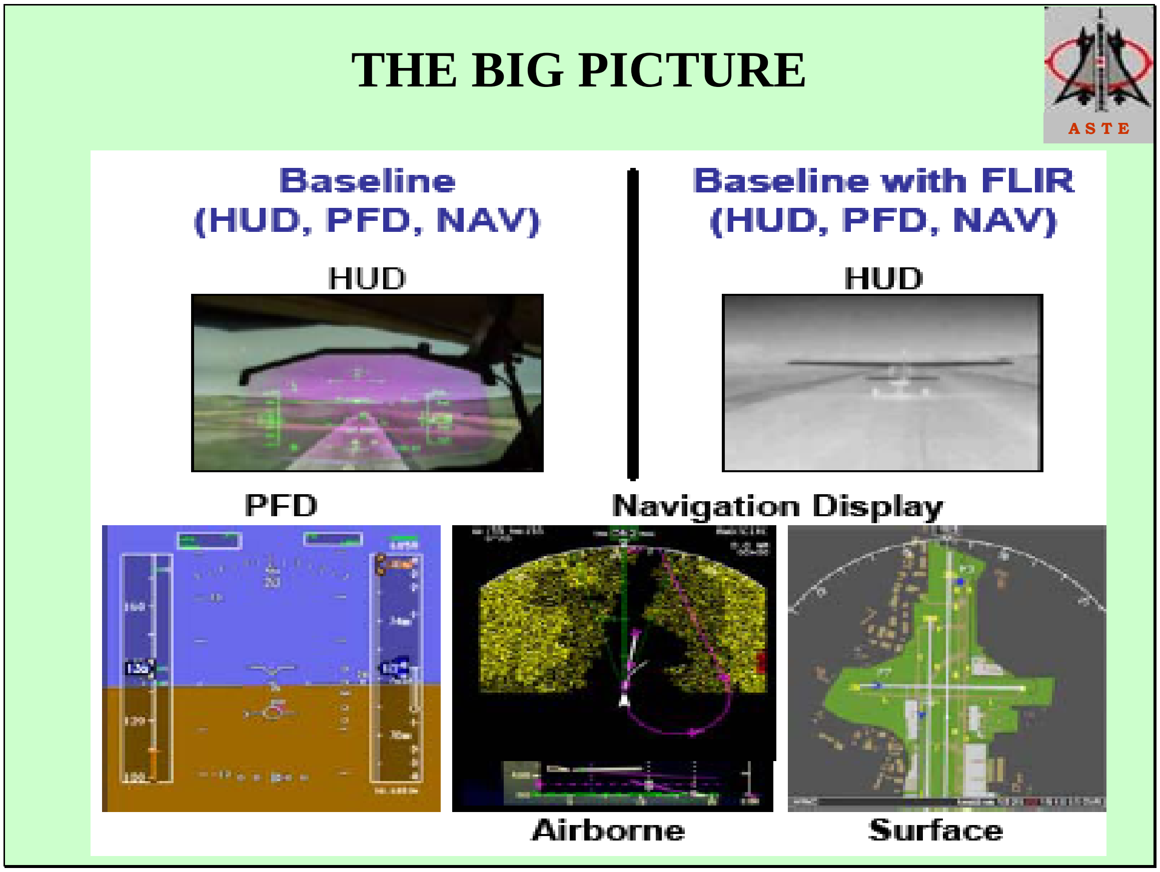
GUIDANCE SYMBOLOGY CONCEPTS

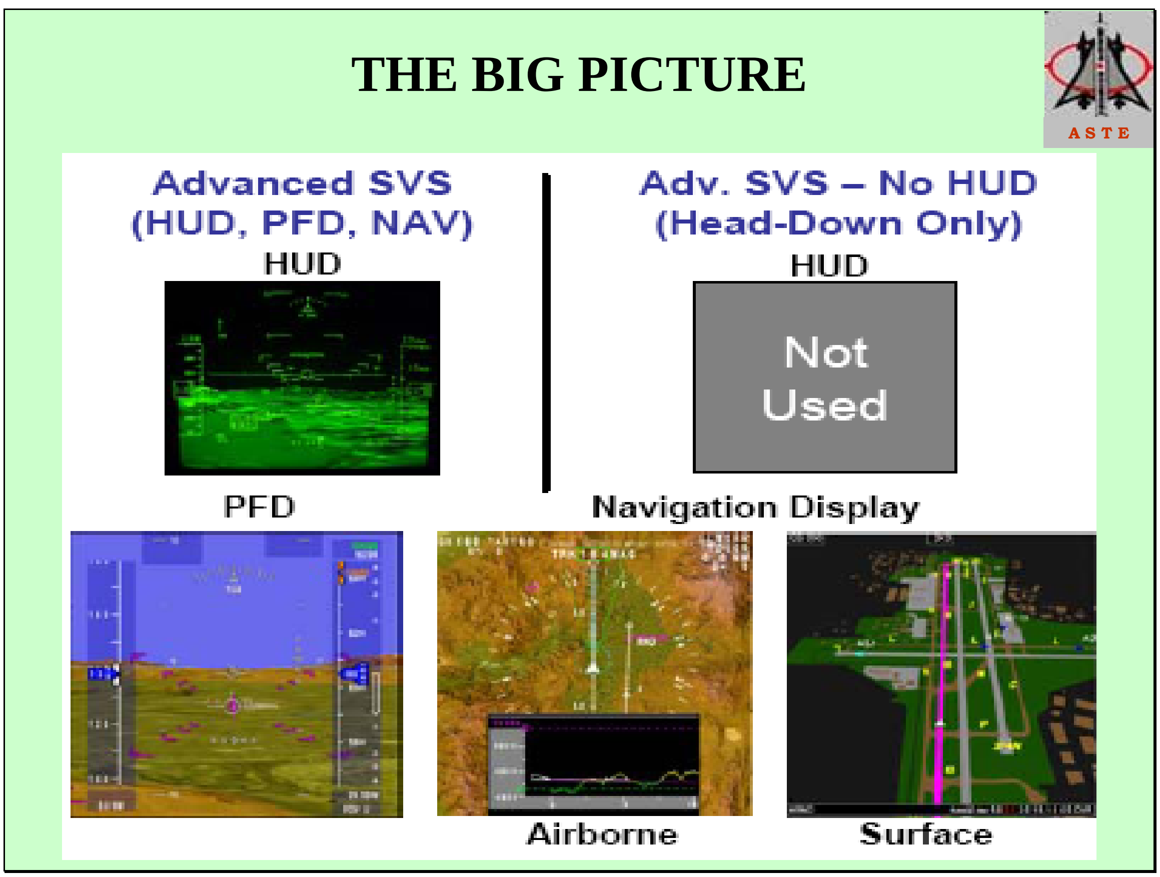
GUIDANCE CONCEPTS



GUIDANCE SYMBOLOGY CONCEPTS

PURSUIT GUIDANCE SYMBOLOGY (TADPOLE OR GHOST) IN CONJUNCTION WITH THE FLIGHT PATH MARKER, WAS WHAT ENABLED THE PILOTS TO ACHIEVE BETTER PERFORMANCE, RATHER THAN THE PRESENCE OF A TUNNEL ITSELF


THE BIG PICTURE
ASTE
Baseline
(HUD, PFD, NAV)
HUD
Baseline with FLIR
(HUD, PFD, NAV)
HUD
PFD
Navigation Display
Airborne
Surface


THE BIG PICTURE
ASTE
Advanced SVS
(HUD, PFD, NAV)
HUD
Adv. SVS – No HUD
(Head-Down Only)
HUD
Not
Used
PFD
Navigation Display
Airborne
Surface

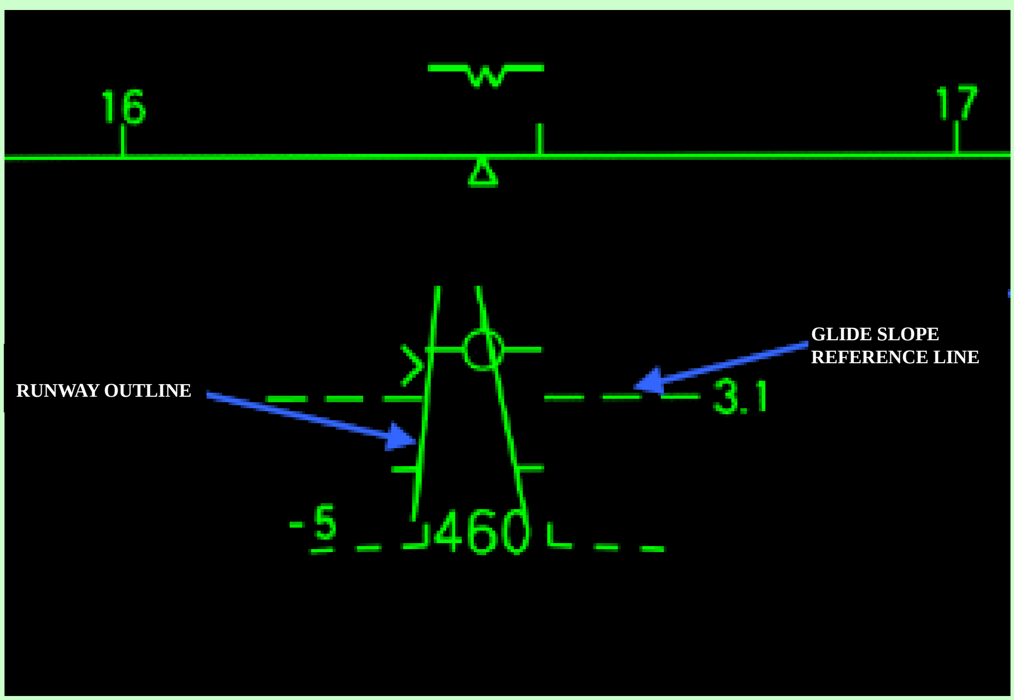
RESULTS

- **NO SIGNIFICANT DIFFERENCE AMONG FOUR DISPLAYS FOR PATH CONTROL PERFORMANCE**

- **MENTAL WORKLOAD**
  ADVANCED SVS < ADVANCED SVS (NO HUD)
  < BASELINE FLIR < BASELINE

- **SITUATIONAL AWARENESS**
  ADVANCED SVS > ADVANCED SVS (NO HUD)
  > BASELINE FLIR > BASELINE

THE INDIAN CONTEXT



THE INDIAN CONTEXT

A ROADMAP

- TEST AIRCRAFT
- PRECISE NAV DATA AND INTEGRITY MONITORING
- DEVELOPMENT OF TERRAIN DATABASE
- DEVELOPMENT OF ADVANCED PATHWAY GUIDANCE
- INTEGRATION OF ENABLING TECHNOLOGIES
- CERTIFICATION

CARRY HOME LESSONS

- NAVIGATION DATA PRECISION NEEDS TO BE OF HIGH ACCURACY (< 1 M)
- REAL TIME MONITORING OF DATABASE INTEGRITY AND TIMELY WARNING OF FAILURES ARE CRUCIAL
- PILOTING ACCURACY IS MORE DEPENDENT ON GUIDANCE SYMBOLOGY AND DISPLAY CONCEPTS.
- SEPARATE TESTING OF ENABLING TECHNOLOGIES AND FINAL INTEGRATION ON TEST AIRCRAFT

CONCLUSION

QUESTIONS?

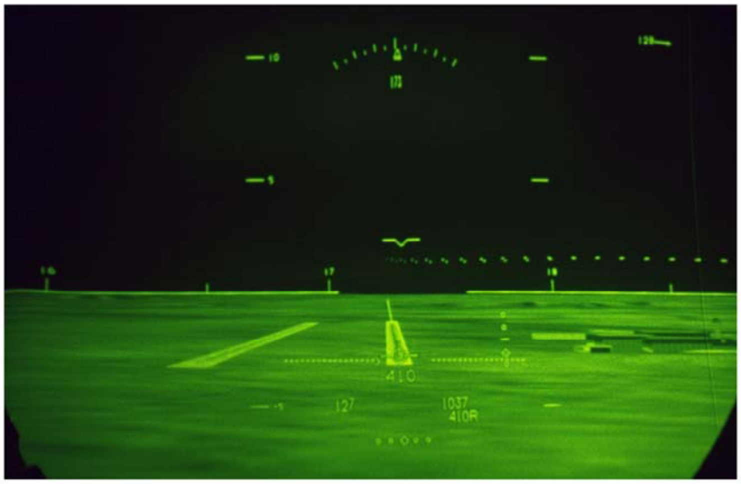


Figure 14. Image of generically textured HUD concept.

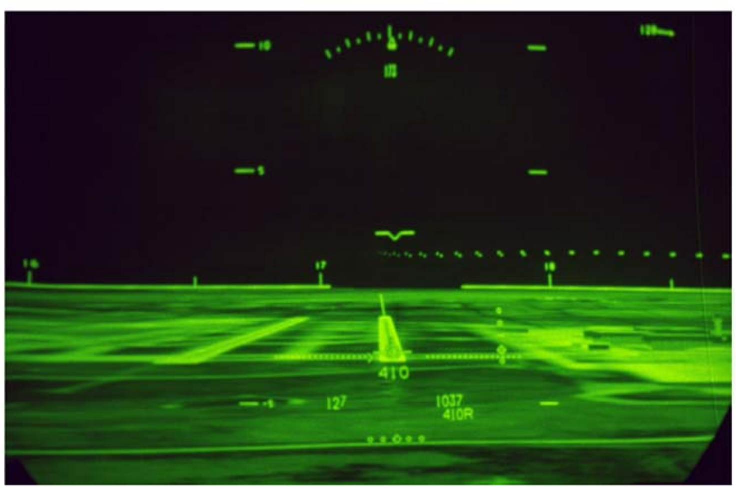


Figure 15. Image of photo realistically textured HUD concept.

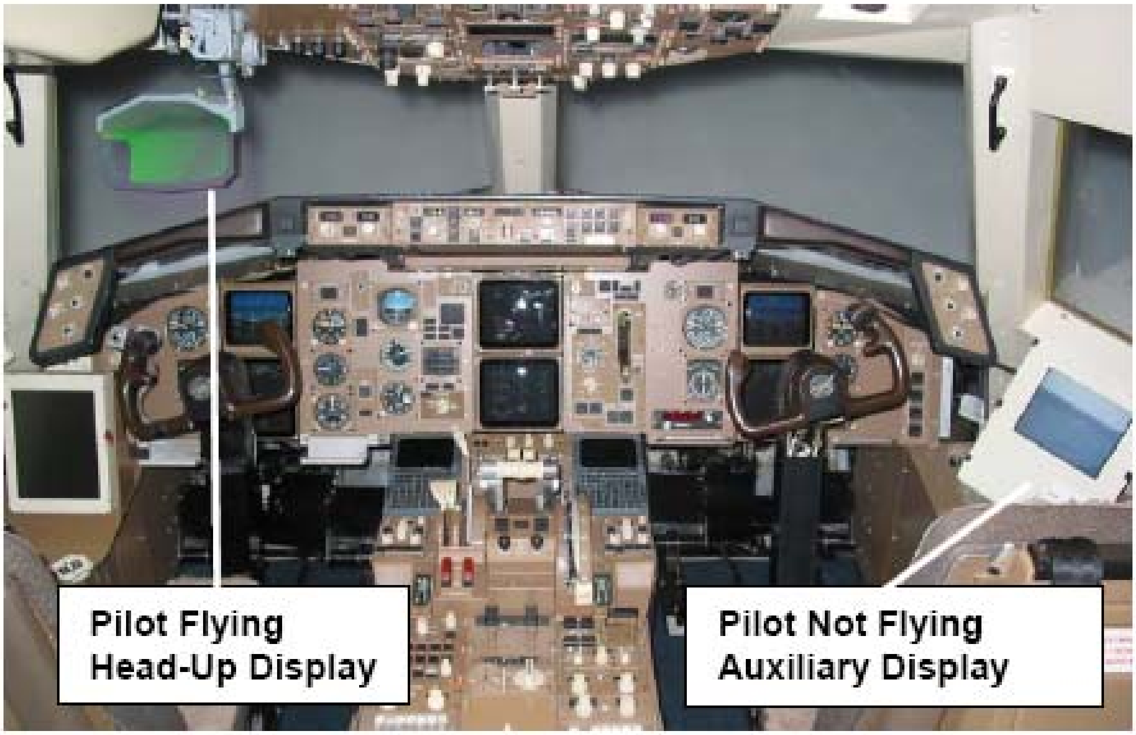


Figure 2. Integration Flight Deck Simulation Facility with HUD and AD.

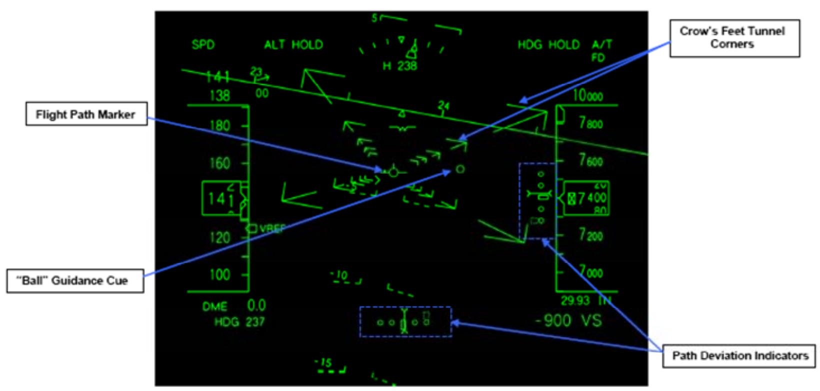
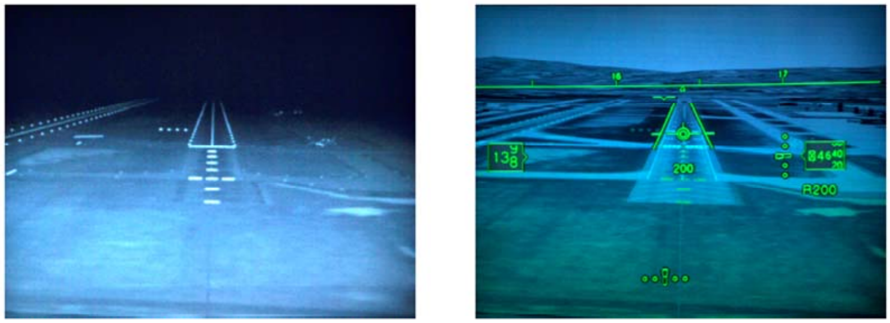


Figure 3. HUD Symbology with Advanced Pathway Guidance.



AD Concept
EVS (FLIR) Only – No Symbology

AD Concept
Fusion – Symbology

Figure 6. Two Auxiliary Display (AD) Formats

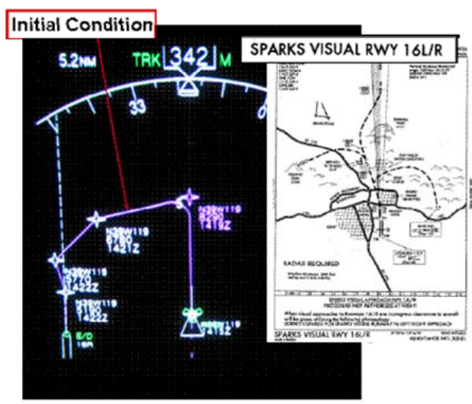


Figure 7. Sparks Visual Arrival to RNO Runway 16R.

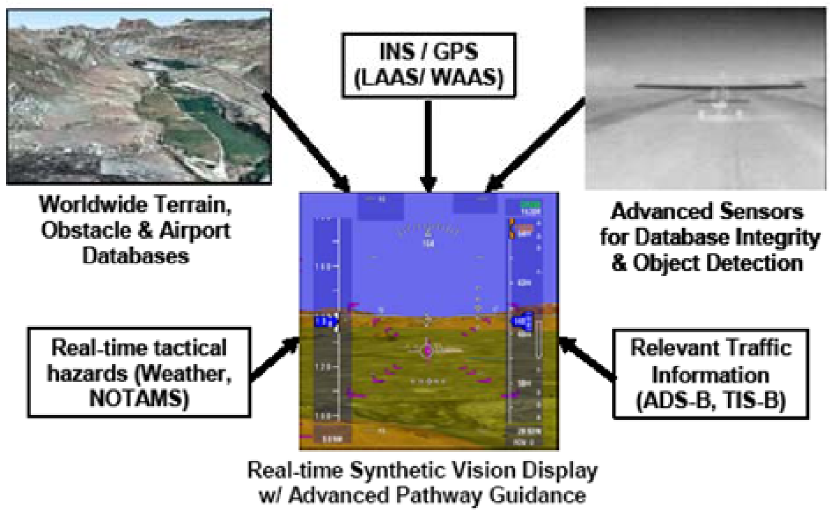
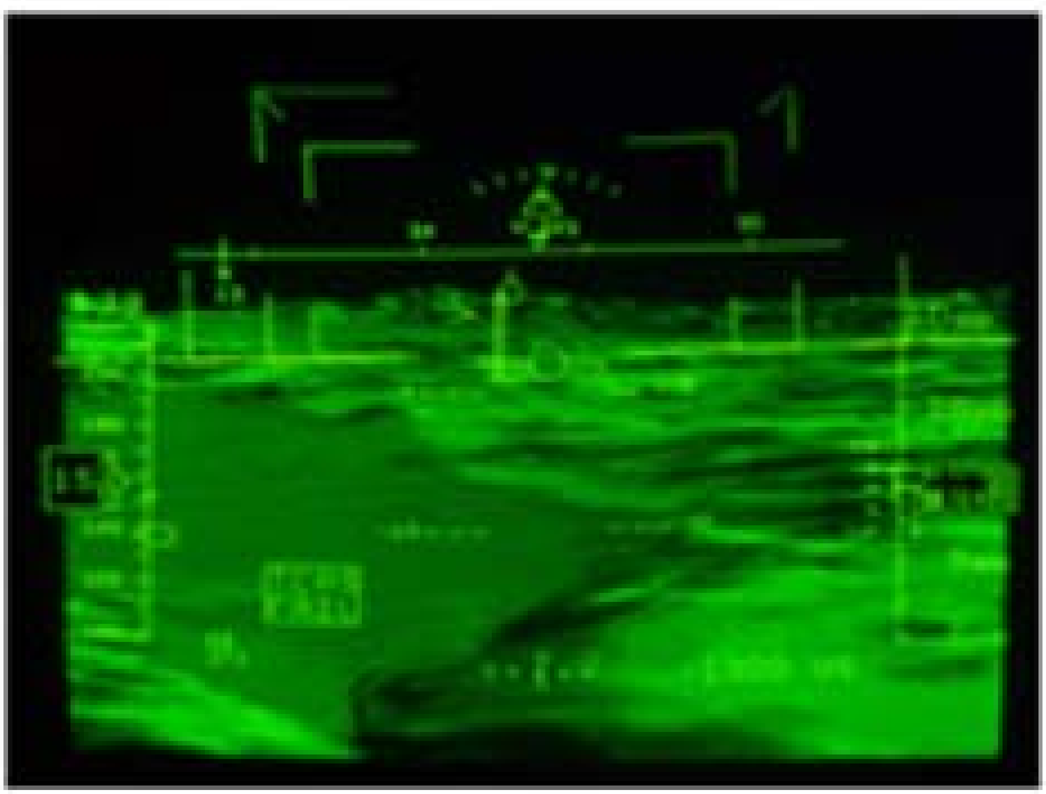
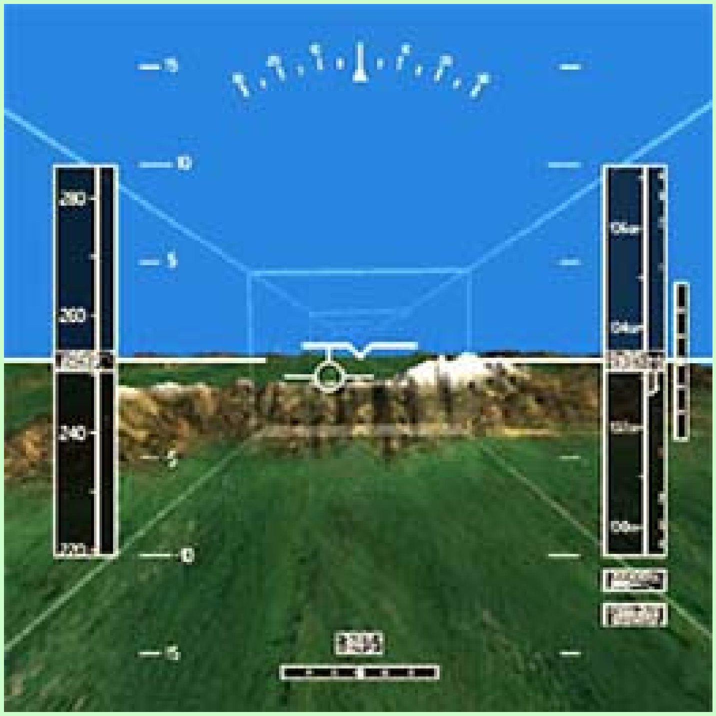
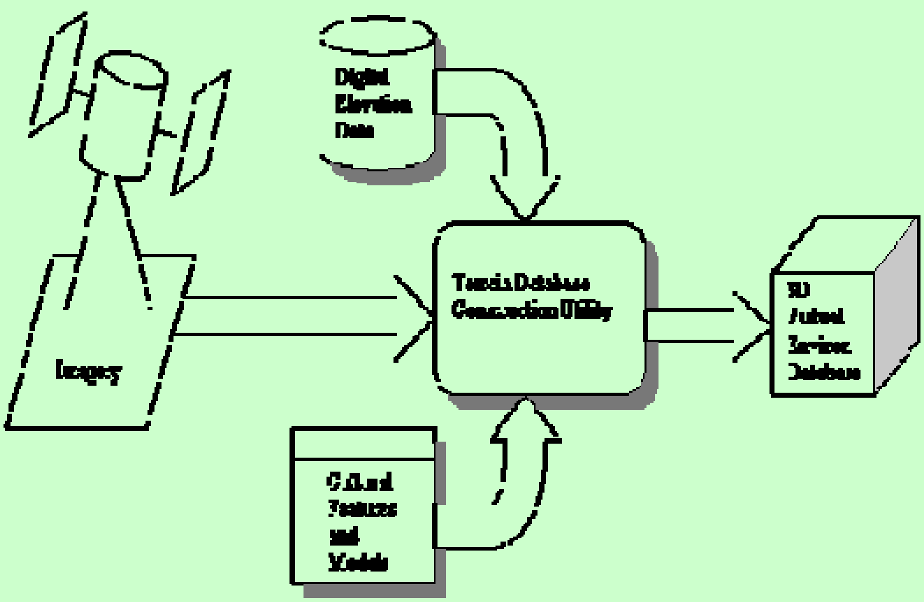


Figure 1: Synthetic Vision System Concept

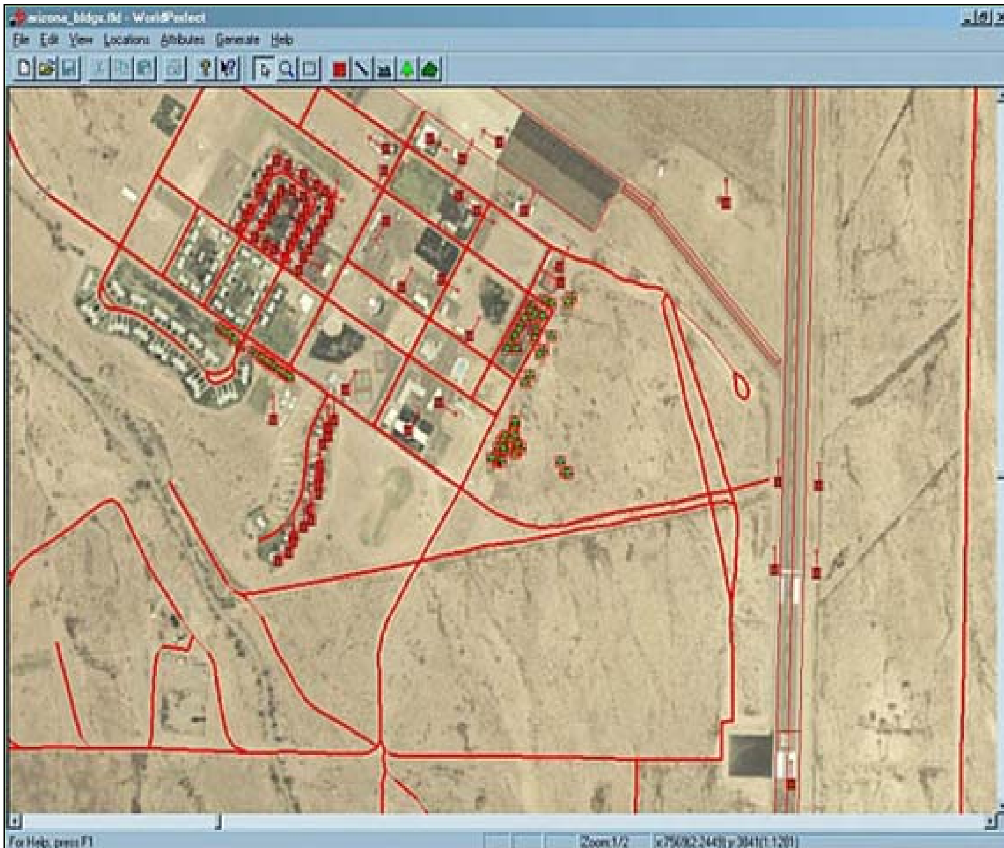




280
260
240
220
10
5



Digital
Elevation
Data
Terrain Database
Construction Utility
Imagery
Features
and
Models
3D
Database



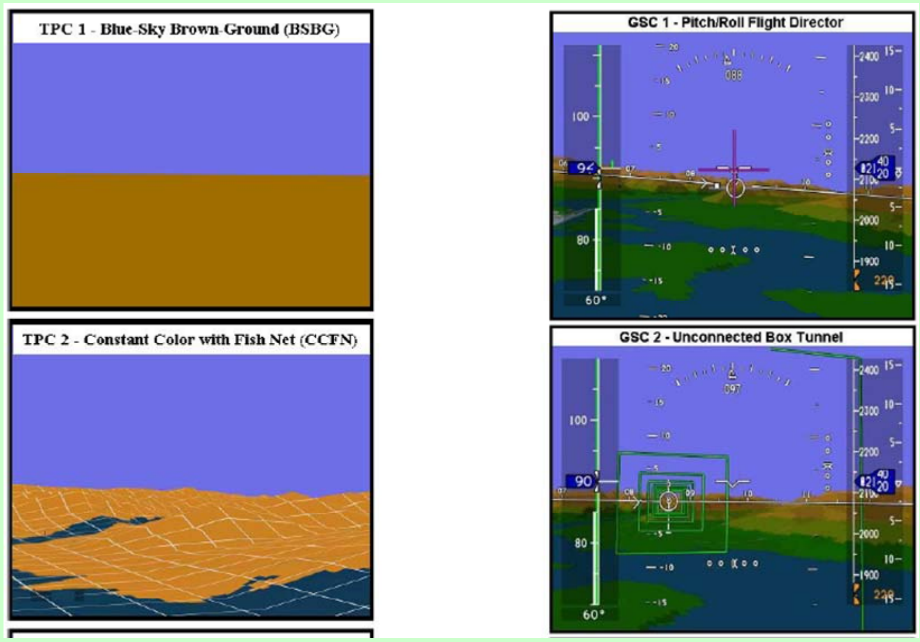
A S T E

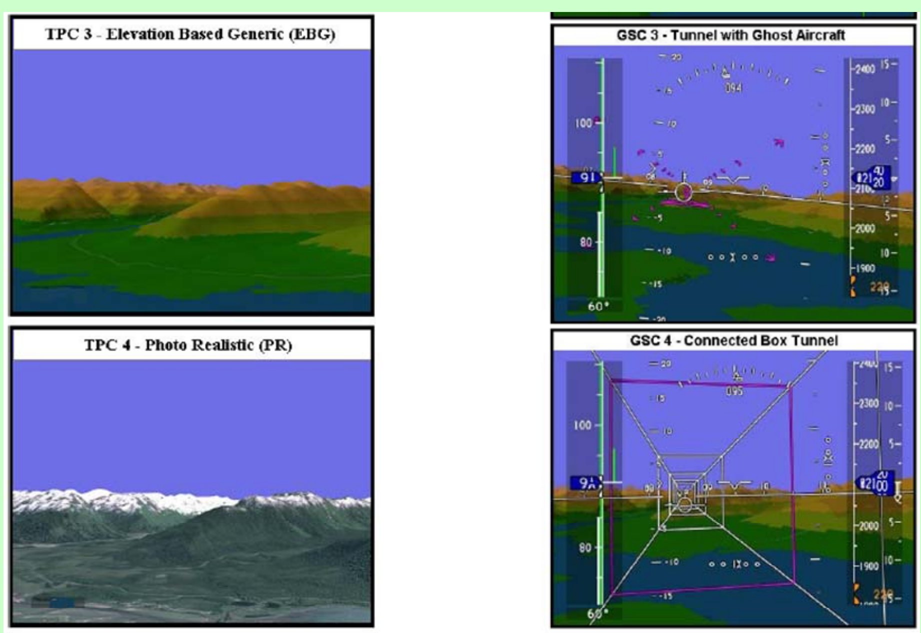
A S T E

Figure 14. SWIR image from daytime flight. Note blooming in foreground.

Figure 15. LWIR image from daytime flight.

Figure 16. Enhanced, registered and fused output.


TPC 1 - Blue-Sky Brown-Ground (BSBG)
GSC 1 - Pitch/Roll Flight Director
TPC 2 - Constant Color with Fish Net (CCFN)
GSC 2 - Unconnected Box Tunnel


TPC 3 - Elevation Based Generic (EBG)
GSC 3 - Tunnel with Ghost Aircraft
TPC 4 - Photo Realistic (PR)
GSC 4 - Connected Box Tunnel

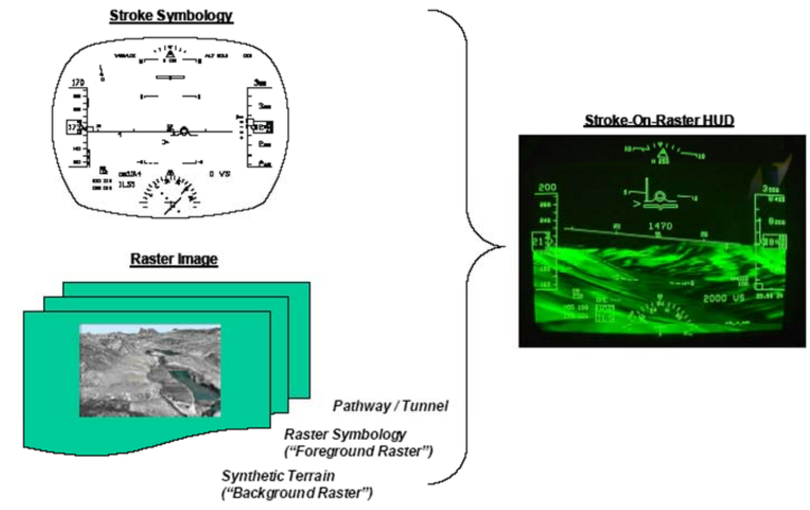


Figure 3. HUD stroke-on-raster imagery components.

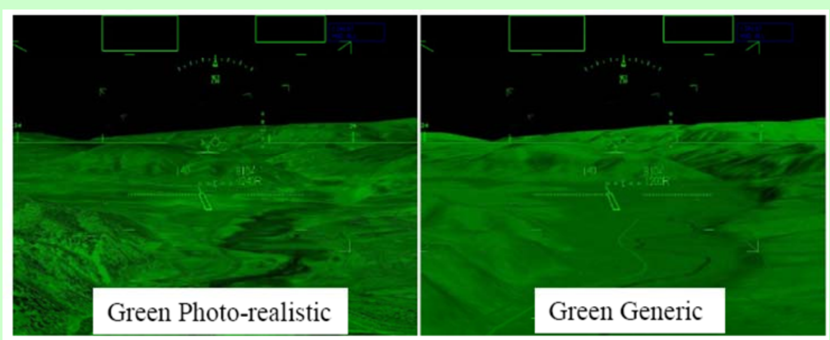


Figure 15. Head-Up Display with generic texturing

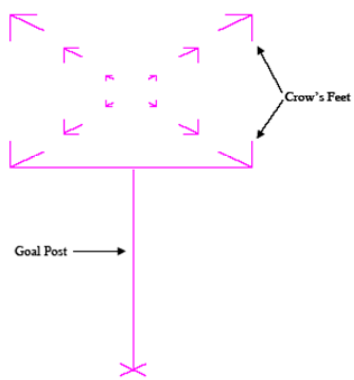
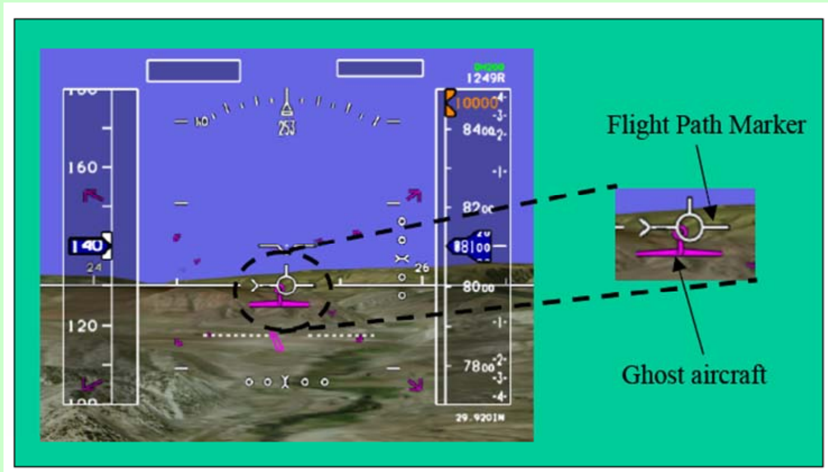


Figure 17. Crow's feet and goal post in the Synthetic Vision tunnel



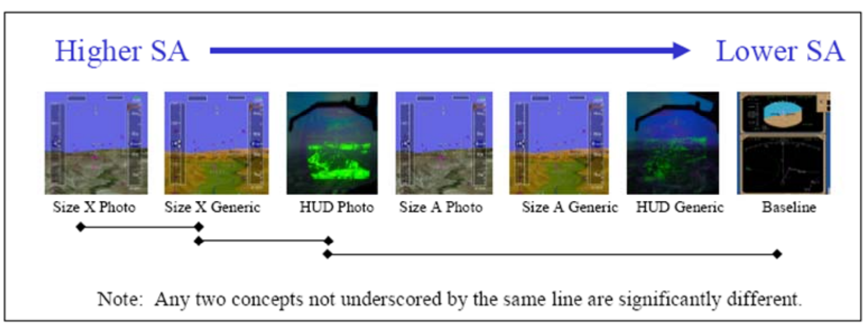


Figure 44. Comparative situation awareness among display concepts.

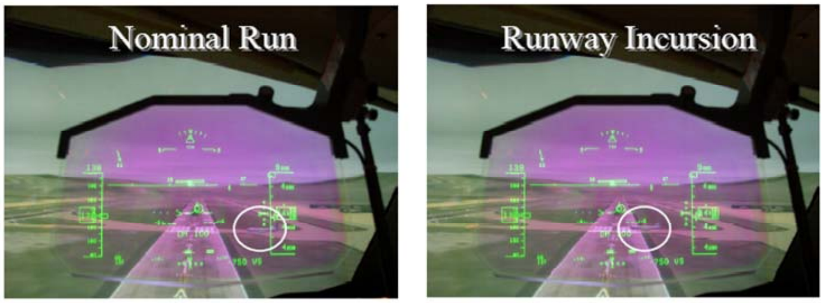


Figure 8. B-737 aircraft in nominal hold position and in runway incursion position.

Speaker Profile

Sqn Ldr J Sreeram graduated from the National Defense Academy, Pune with a Bachelors degree in Science in Jun 95. He was commissioned as a fighter pilot in the IAF in Jun 96. During the last twelve years he has flown more than 1000 hours on the Mig 21 variants including the Bison. He is a Fighter Combat Leader -- a graduate of the prestigious Tactics and Air Combat Development Establishment at Gwalior. He is also a 07A graduate of the USAF Test Pilot School Edwards, CA wherein he flew more than 25 different aircraft including F-16D, F-15E and the C-17 Globe master. He is presently serving as a test pilot in Aircraft and Systems Testing Establishment, Bangalore

Computer Graphics for Modern Cockpits and Cockpit Procedure Trainers

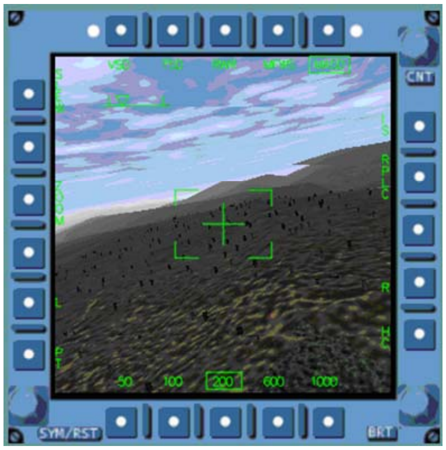
VS Renganathan, Director, Coral Digital Technologies Private Ltd.

The glass cockpit of the near future is expected to fuse advanced sensor technologies with video and advanced computer graphics to present the pilot with a fault tolerant and virtually real situational awareness for both navigation and high gain tasks such as landing or station keeping even in conditions of impaired visibility or darkness.

The GPS coupled with WAAS provides highly accurate location information for aircraft enabling en-route navigation and precision approach and landing. Digital terrain data (available from SRTM), geo-specific textures (available from satellite and aerial images) and advanced 3D rendering software and hardware could augment pilot vision with virtual reality and either overlay 3D imagery over video of actual terrain view to enhance visibility.

In this lecture we present the capabilities available in Coral Digital towards using virtual reality in modern cockpits and cockpit procedure trainers. We present the software and hardware suitable for such applications.

COMPUTER GRAPHICS FOR MODERN COCKPITS AND COCKPIT PROCEDURE TRAINERS



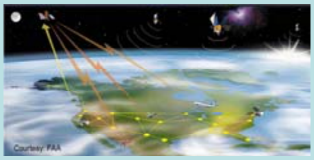
CORAL DIGITAL TECHNOLOGIES PVT. LTD.

- **VS Renganathan**
- **K Kirubananthan**
- **V Jeevitha**

SCOPE

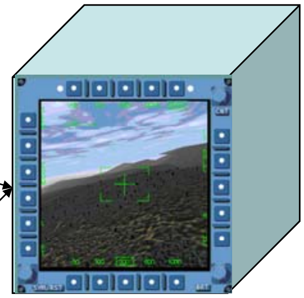
I	SCHEME
II	COMPUTER GRAPHICS
III	COMPUTER AND GRAPHICS HARDWARE

SCHEME



GPS – WAAS (1-2m accuracy)

ONBOARD ATTITUDE SENSORS



Onboard Computer Generates Virtual Image of Terrain to allow pilot to navigate and perform approach for landing in all weather and visibility conditions

I	SCHEME
II	COMPUTER GRAPHICS SOFTWARE
III	COMPUTER AND GRAPHICS HARDWARE

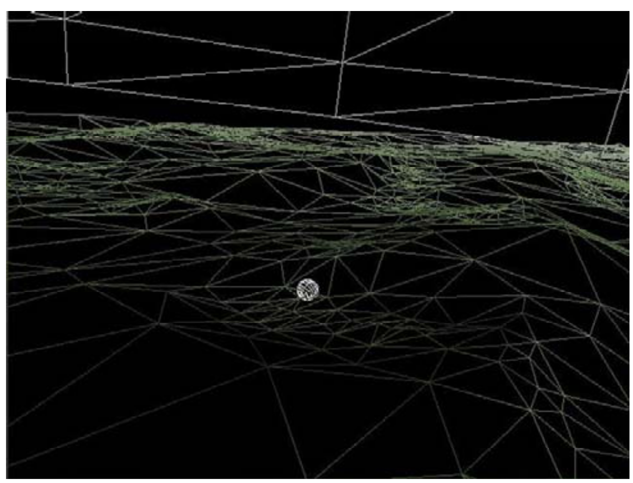
ENABLING TECHNOLOGIES

- COMPUTER GRAPHICS SOFTWARE
- TERRAIN DATA FROM SRTM
- GEO-SPECIFIC TEXTURES FROM SATELLITE/AERIAL IMAGERY
- GPS-WAAS/MSAS/EGNOS
- COMPUTER GRAPHICS HARDWARE

EMBEDDED SINGLE BOARD COMPUTERS ARE BECOMING AS POWERFUL AND POSSESS ADEQUATE RESOURCES TO HANDLE THE 2D/3D GRAPHHICS DEMANDS OF THIS SOLUTION.

COMPUTER GRAPHICS SOFTWARE

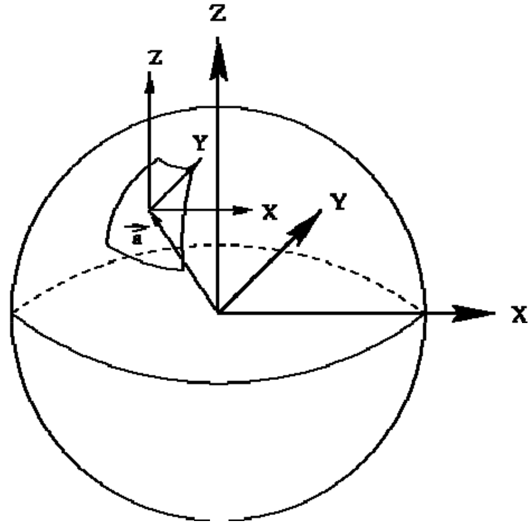
- GRAPHICS LIBRARY – OpenGL (2D and 3D)
- TESSELATION OF TERRAIN DATA – SRTM DATA, 90 m grid (3 arc sec)



COMPUTER GRAPHICS SOFTWARE

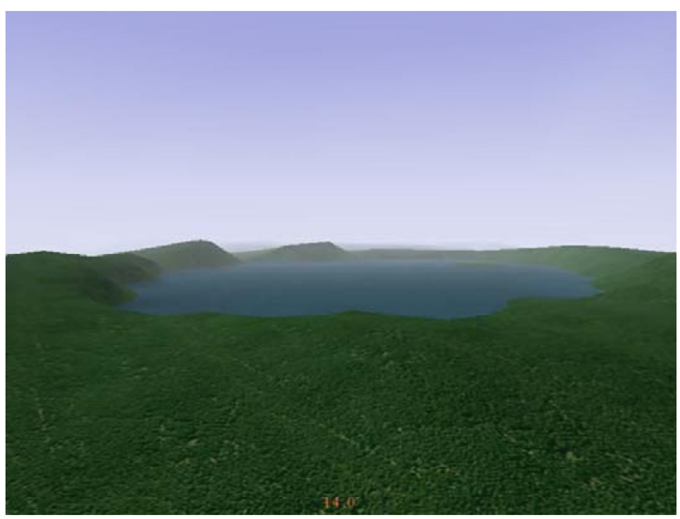
- PARTITIONING TERRAIN DATA

Latitude Range	Tile Width
[0, 22)	$\frac{1}{8}$ degree
[22, 62)	$\frac{1}{4}$ degree
[62, 76)	$\frac{1}{2}$ degree
[76, 83)	1 degree
[83, 86)	2 degrees
[86, 88)	4 degrees
[88, 89)	8 degrees
[89, 90]	polar cap



COMPUTER GRAPHICS SOFTWARE

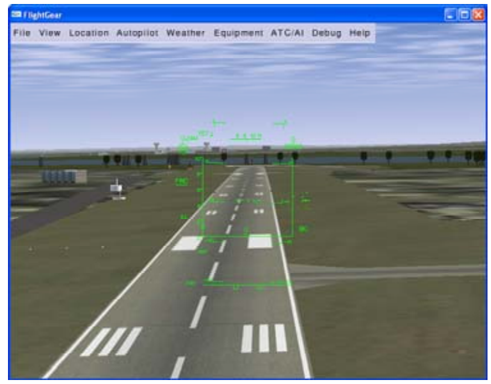
- CULLING AND RENDERING



COMPUTER GRAPHICS SOFTWARE

OPEN SOURCE SOFTWARE

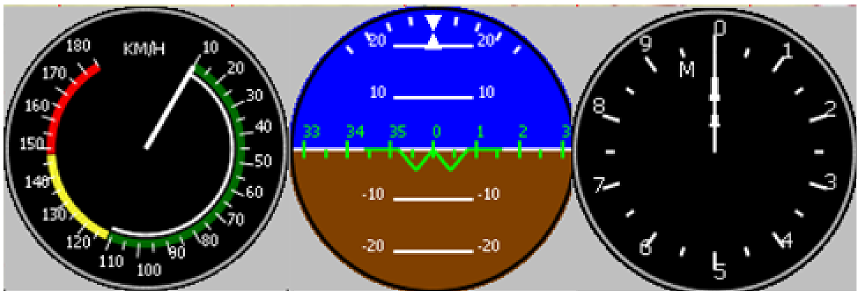
- FLIGHTGEAR www.flightgear.org
    - TOOLS FOR TERRAIN DATA GENERATION
    - IMAGE GENERATOR



COMPUTER GRAPHICS SOFTWARE

HUMAN MACHINE INTERFACE – HEAD UP / MULTI FUNCTION DISPLAYS

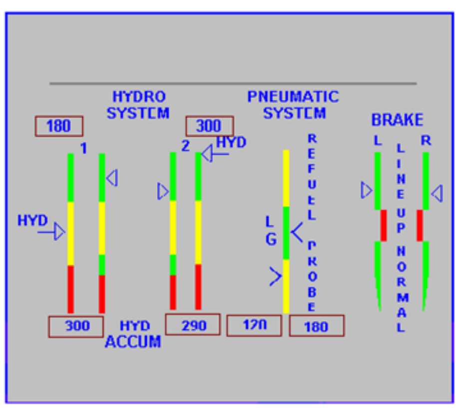
- 2D GRAPHICS FOR GLASS COCKPITS
  - DIALS & GAUGES - HORIZON, ALTIMETER, VSI, TSI etc.



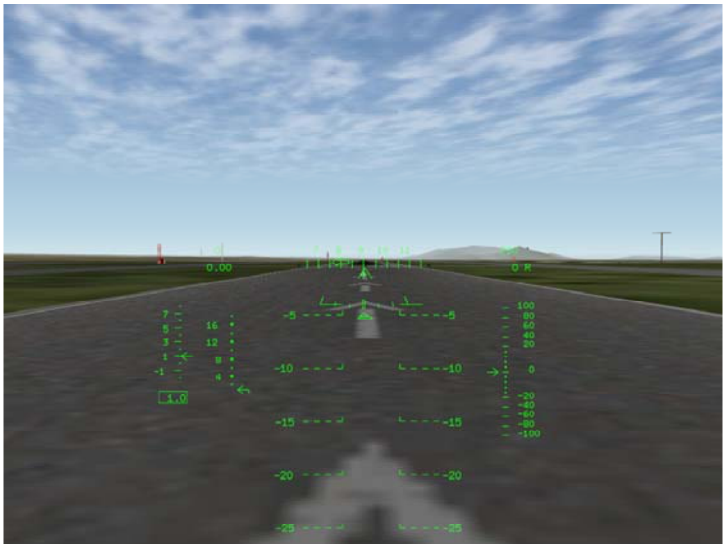
COMPUTER GRAPHICS SOFTWARE

HUMAN MACHINE INTERFACE – HEAD UP / MULTI FUNCTION DISPLAYS

- 2D GRAPHICS FOR GLASS COCKPITS
  - EQUIPMENT STATUS DISPLAY – FUEL QTY, HYDRAULICS etc.

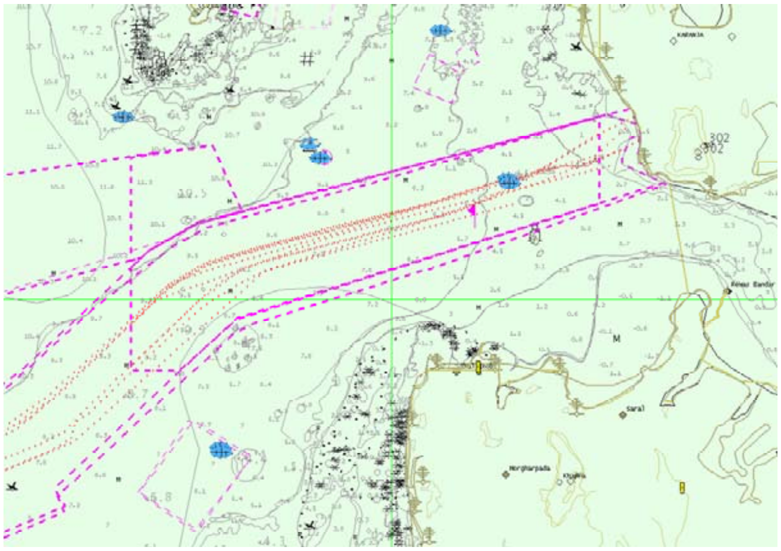


COCKPIT PROCEDURE TRAINER - IMAGE GENERATOR FOR OWI

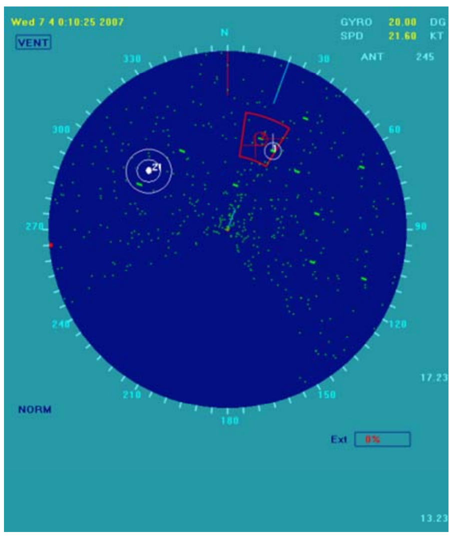


COCKPIT PROCEDURE TRAINER - IMAGE GENERATOR FOR OWI

2D VECTOR MAPS FOR NAVIGATION



RADAR DISPLAY



HEAD UP DISPLAY

I	SCHEME
II	COMPUTER GRAPHICS SOFTWARE
III	**COMPUTER AND GRAPHICS HARDWARE**

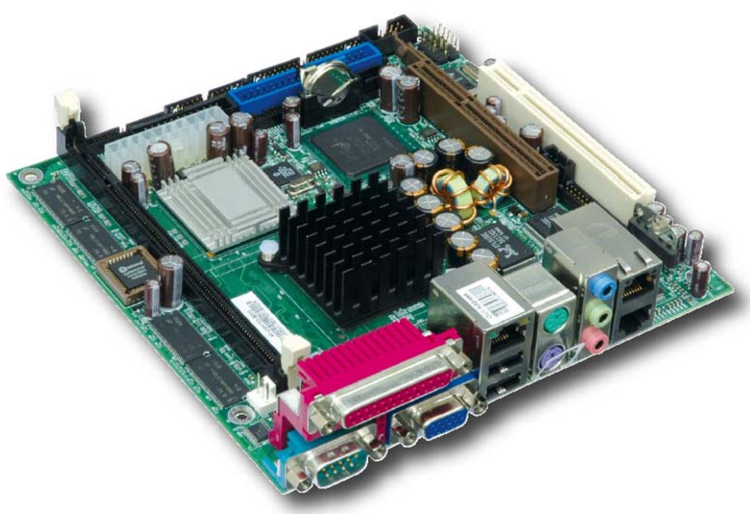
COMPUTER AND GRAPHICS HARDWARE

KONTRON

3.7” x 4.5”

Onboard 3D Graphics

COMPUTER AND GRAPHICS HARDWARE



KONTRON

7” x 7”

External Graphics

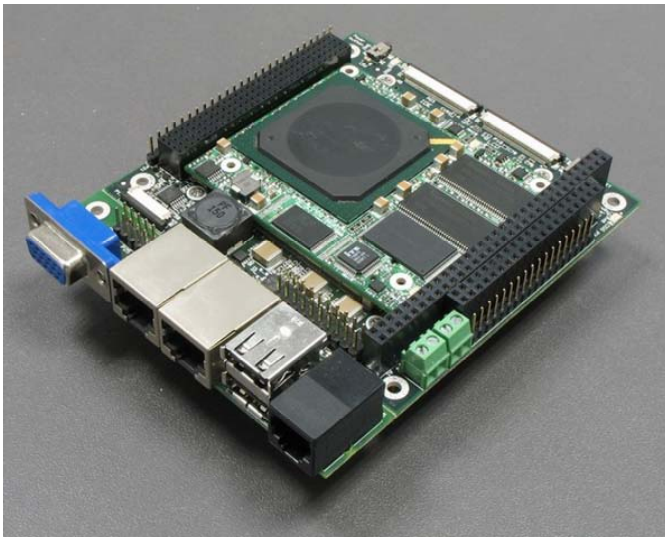
COMPUTER AND GRAPHICS HARDWARE

AMD

3” x 3”

2D/3D Graphics

COMPUTER AND GRAPHICS HARDWARE



COMPULAB

4.3” x 3.5”

2D Graphics

Speaker Profile

VS Renganathan, Founder Director has over 25 years engineering experience

Educational Qualification

ME, Aerospace Engineering, IISC, Bangalore

B.TECH, Mechanical Engineering, Naval College of Engineering, Lonavla

BSC., National Defence Academy, Khadakvasla

Experience

(Oct. 05 – Till Date) Director, Coral Digital Technologies, Bangalore

(May 03 – Sep. 05) CTO, Realsim Technologies, Bangalore

(Jun. 97 – Apr. 03) Deputy Project Director, ADA, Bangalore

(Jul. 95 – May. 97) Marine Engineering Officer, INS Khurki

(Mar. 94 – Jun. 95) Air Engineer Officer, Indian Naval Air Squadron 310

(Feb. 93 – Feb. 94) LCA Navy Project Team, ADA

(Jul. 82 – Feb. 93) Various Appointments in Indian Navy

Publications

"PCs in Flight Simulation Research – The LCA (Navy) Experience", presented at International Conference on Flight Simulation Technology and Training, Moscow, 24-25 May 2002.

http://www.flightgear.org/Papers/ADAPaper/UsingPCsForFlightSimulationResearch.html

Visuals for Real-Time Flight Simulator

K P Srikanth, Moncy J. Thomas and P. Lathasree,

Simulation Group, FMCD, NAL, Bangalore

Providing pilots with Synthetic Vision (SV) displays containing terrain information, Head-Up-Display (HUD) and Head-Down-Displays (HDD) has the potential to improve flight safety by improving situational awareness and thereby reducing incidents of aircraft accidents. This Synthetic vision provides the pilots with virtual view of the Out-The-Window (OTW) terrain even in bad weather conditions and poor navigation facilities. This paper presents the design and development of OTW visuals consisting of 3D terrain, HUD and HDD, which provide essential cues for the pilot during flight. These are the Computer generated images based on navigation inputs. The terrain database comprises of the Digital Terrain Elevation (DTED) Level 1 Elevation Data textured with high resolution Satellite Data, in and around HAL Bangalore International airport and Google Earth imageries for the surrounding areas. The conceptual studies on the level-of-detail algorithms for rendering terrain database are also presented. Terrain database integrity monitoring is an important aspect of Synthetic Vision. A study carried out for the Terrain Database Integrity Monitoring will be discussed. Interface software for Level 2 Elevation Data gathered with Shuttle Radar Topography Mission (SRTM) has been developed. This includes the interpretation of Radar Altimeter data together with GPS NAV. The above methodologies have been successfully incorporated at different simulators in NAL, India and DLR, Germany. These technologies are relevant to Enhanced Vision System of the Regional Transport Aircraft being designed and developed indigenously for the first time in India

Visuals for Real-Time Flight Simulator

Srikanth K P, Moncy T Thomas, P Lathasree

Flight Mechanics and Control Division

National Aerospace Laboratories

Bangalore

Overview

Introduction

- Enhanced and Synthetic Vision System (ESVS)
- DELS Flight Simulator facility at NAL

Importance of Visuals

Expertise gained in development of Visual System towards ESVS

- Synthetic Vision - OTW Visuals, HUD and simulated MFDs
- Case Study 1 : LOD Management for realistic visuals
- Case Study 2 : Terrain Data Integrity Monitoring

Conclusion

Enhanced and Synthetic Vision (ESVS)

Definition of ESVS according to Air Transport Association (ATA) :

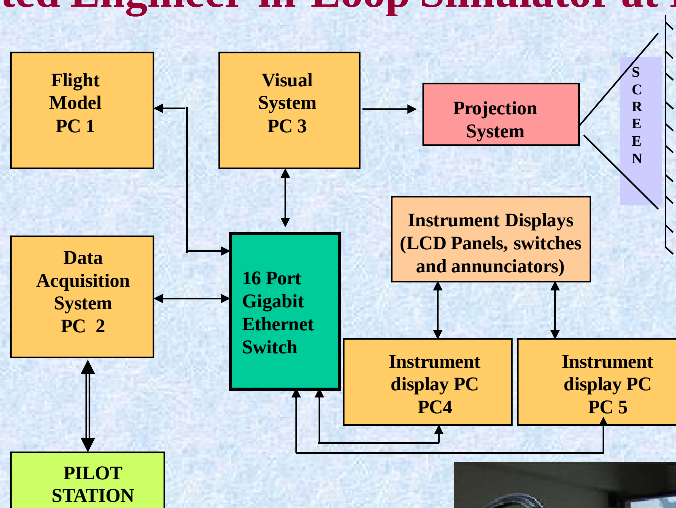
"... means to safely increase airport capacity and reduce runway incursions in low visibility conditions, without significant expansion of ground facilities

Combination of Sensor Vision and Synthetic Vision

Sensor Vision consists of several imaging sensors that are digitally fused together to give a pilot a better view of the outside world even in challenging visual conditions.

Synthetic Vision usually generates a virtual out-the-window view (OTW)

Distributed Engineer-in-Loop Simulator at NAL



- Fixed Base
- Real Time
- Multiple PCs (COTS, High Performance GPU)
- Simulated Cockpit, Actual pilot controls
- **Visuals**

Visuals System Components

Visual System

3D-terrain-model and 3D objects, Texture Files Real-time Render Engine

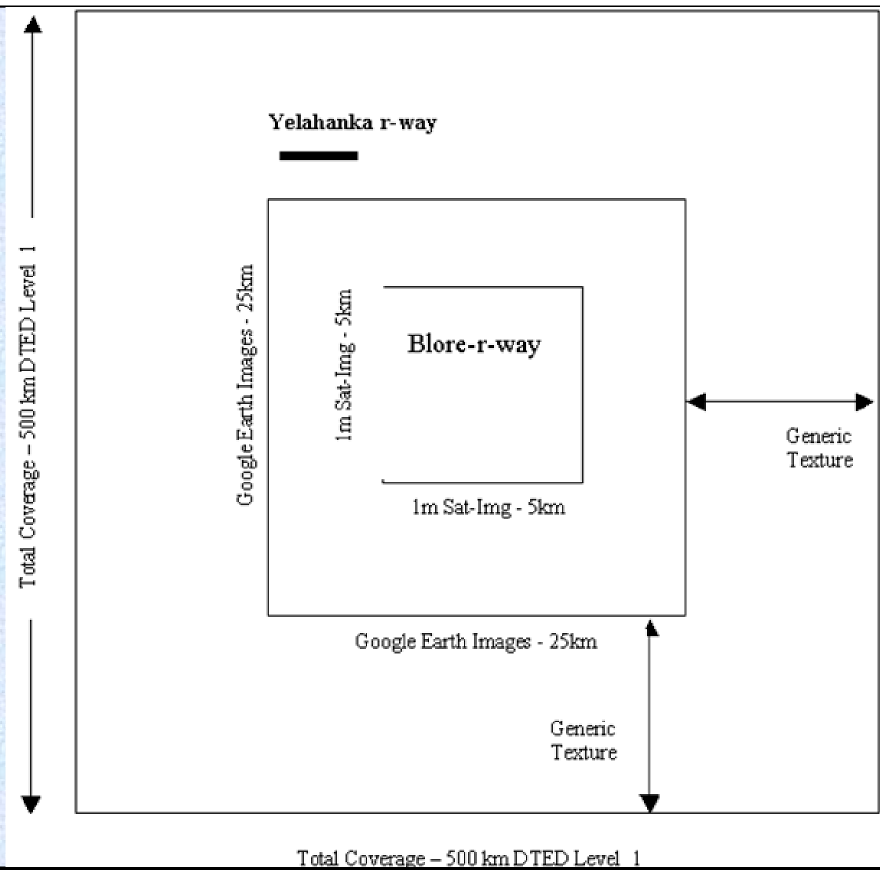
OTW - IRIS GL, Coryphaeus, OpenGL Performer, Multigen Tools

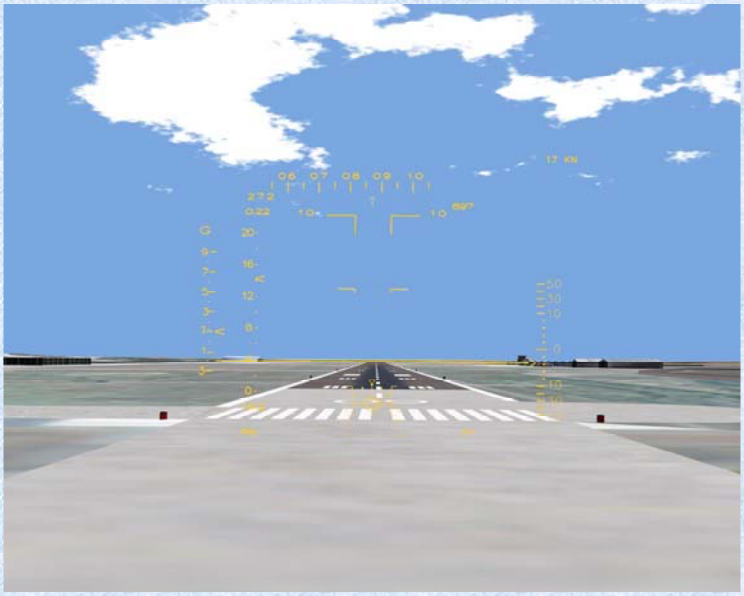
HUD – IRIS GL, OpenGL

HDD – GL Studio Software (Multi Function Displays)

Synthetic Visuals

OTW rendered image of an ***a priori*** database of **Satellite Imagery, Aerial Photographs, Google Earth images with DTED Level 1 for High Fidelity Visuals**





OTW visuals superimposed with HUD

Simulated MFD Pages

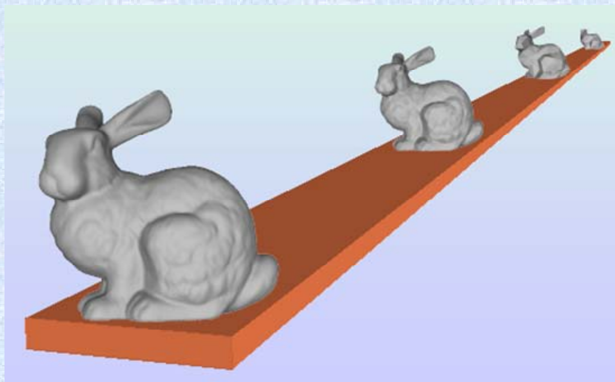
Case Study 1

Level of Detail Concept for Visuals

Work Carried out at Institute of Flight Systems, DLR, Braunschweig, Germany

by

Moncy T. Thomas



Level of Detail Concept for Visuals

Essential for a pilot to have terrain database with detailing at various levels as a part of the realistic visuals

Display Performance Parameters

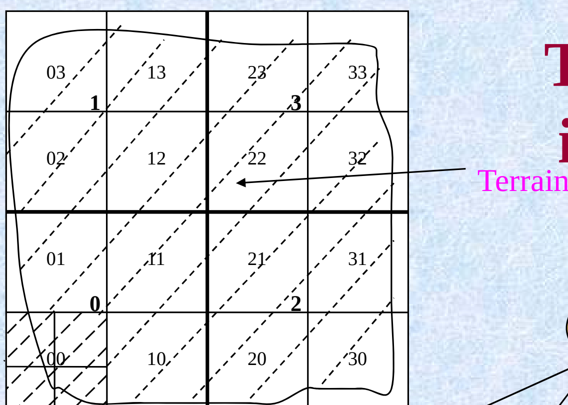
- **Frame Rate**
- **Frustum**
- **Texture (Satellite Image, Google Earth Images, DTED Data)**

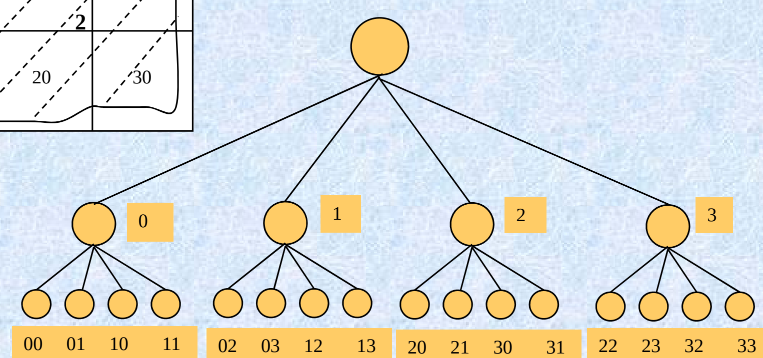
➢**Graphics systems can display only a finite number of geometric primitives per frame at a specified frame rate. Because of these limitations, the fundamental problem of database construction for real-time simulation is to maximize visual cues and minimize scene complexity. Hence it is essential to implement some form of Level Of Detail (LOD) management for the terrain loading**

Concepts of quad tree LOD

- The render engine should perform the LOD management for 3D geometry data and textures
- One of several similar models of varying complexity is displayed based on how visible the object is from the eye point.
- Hierarchical data structure - a quad tree

Terrain divided into quadrants

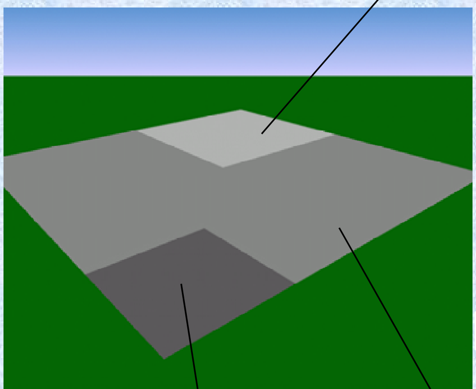




Quad Tree Organisation of the terrain

Illustration of LOD

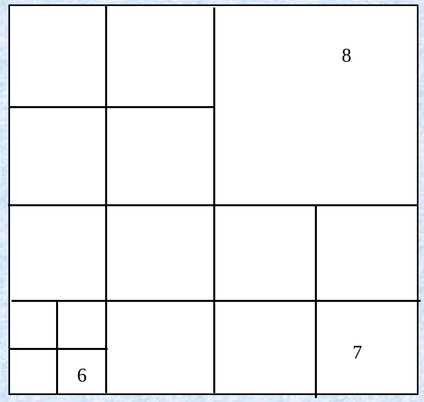
Lod 8



Eye

Lod 6

Lod 7



One lod 7 is replaced by 4 tiles of lod 6 - front

Eleven tiles (4 + 4 + 3) of lod 7 - middle

One tile of lod 8 - far end

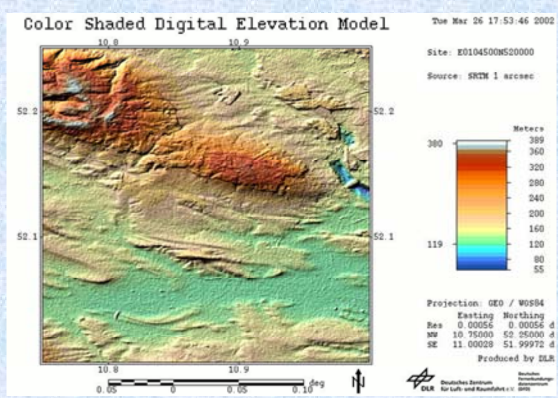
Case Study 2

DTED Integrity Monitoring for Synthetic Vision

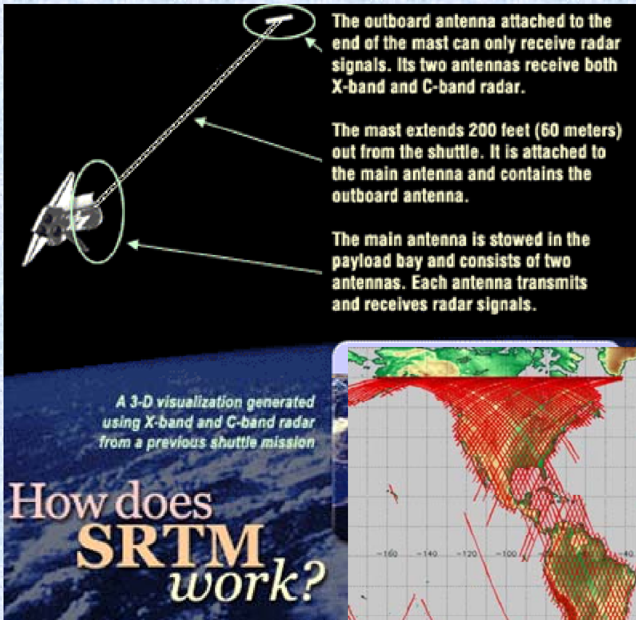
Work Carried out at Institute of Flight Guidance, DLR, Braunschweig, Germany

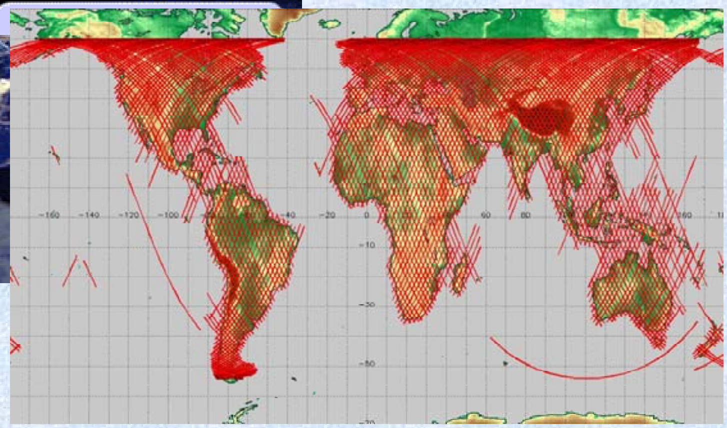
by

P Lathasree



SRTM Elevation data





60° North – 58° South

SRTM – Coverage

DTED Integrity Monitoring for Synthetic Vision

Interface Software for data gathered with Shuttle Radar Topography Mission (SRTM) and validation

Objective of SRTM Interface Software

- ❖ to extract the elevation data from the source binary files, corresponding to the given longitude and latitude and
- ❖ compare this elevation data with the interpretation of Radar Altimeter data together with GPS NAV.

Application areas:

- Flight Simulation
- Usage and Interpretation of Radar Altimeter data together with GPS
- Ground Mapping of Radar Images
- Terrain correlation for the Navigation support

Digital Elevation Models

Digital Elevation Model is a computerised representation of Earth's Terrain

Described either by a wire frame or an image matrix in which, the value of each pixel is associated with a specific topographic height.

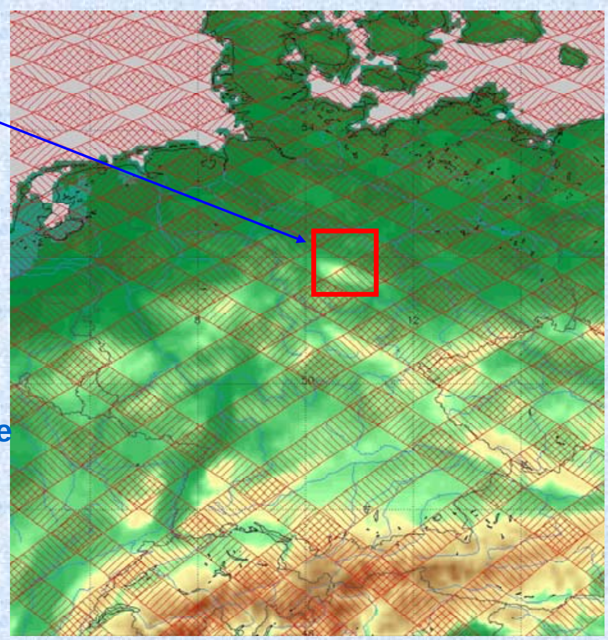
Commonly, terrain heights are expressed as grey values on a scale ranging from black (minimal height) to white (maximal height).

A data file of DTED is a cell defined by latitude and longitude of a geographic reference system. The terrain elevation information is expressed in meters.

SRTM Data based on DTED - MIL 89020B Performance Specifications

SRTM Coverage of Germany

Braunschweig



10.25 ° – 11.25 ° Longitude

51.50 ° – 52.25 ° Latitude

Braunschweig SRTM Elevation Data

DTED Level 2 data with 1 second of arc (~30m) latitude and longitude

Easting 10 and 11 , Northing 51 and 52

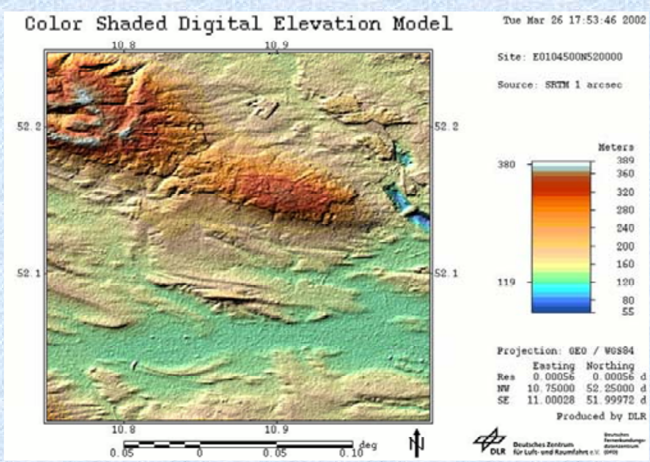
with 15 arc minute size (0.25deg) raster length in latitude and longitude

(i.e. 10.25 - 11.25 deg longitude and 51.50 - 52.50 deg latitude

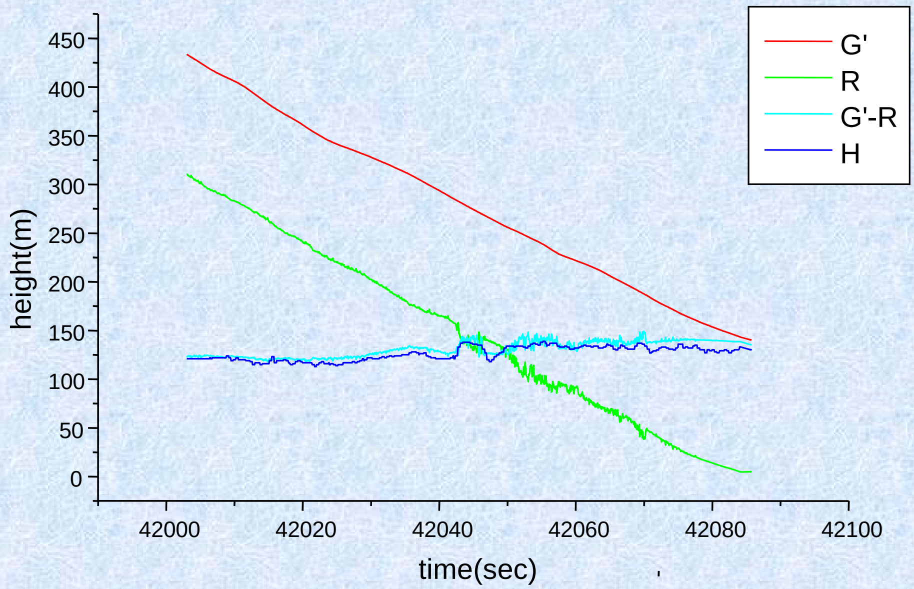
with 0.25deg length in longitude and latitude for each tile)

15sets of tiles - supplied as binary files (DEM for elevation) along with the corersponding 15 source image files

SRTM Source Image File



Comparison of DO-228 data and SRTM elevation

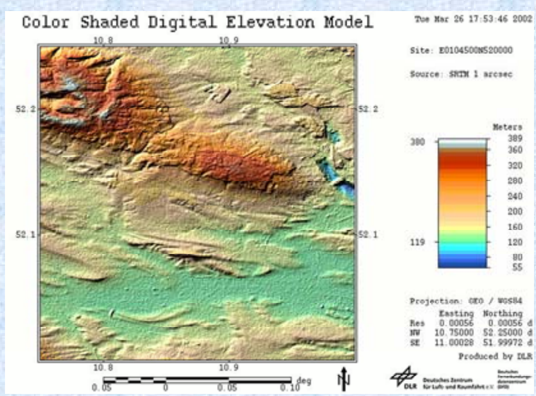


G’	GPS Altitude with reference as WGS 84 Ellipsoid
R	Radar Altitude(filtered height)
H	SRTM Elevation

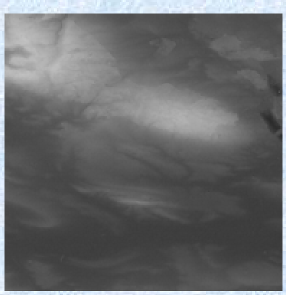
G’ - H = R or

G’ - R = H

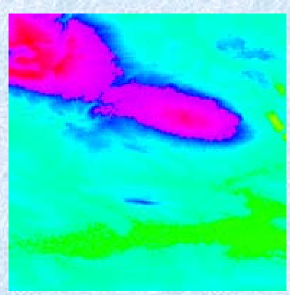
Validation of SRTM Interface software based images against source images



Source image



Grey code image



Colour coded image

SRTM Software generated images

Conclusions

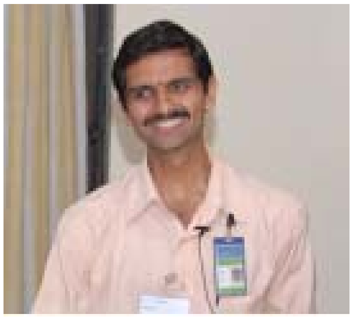
- Out of the Window Visuals along with the HUD and HDD are implemented for a flight simulator
- Visuals Performance enhancement using LOD Management concept
- DTED Integrity Monitoring using SRTM elevation data and DO 228 flight data (GPS and RADALT)

Future Work to realise ESVS at NAL for RTA

Combining the technology know-how on Synthetic Vision with the Multi Sensor data fusion (Enhanced Vision) to provide pilot with realistic visual effects under low visibility conditions, without significant expansion of ground facilities

THANK YOU

Speaker Profile



Srikanth K P obtained B.E. degree from Bangalore University in 1992 and completed M.S. degree in Software Systems from BITS, Pilani in 1995. He is working as Scientist in Simulation Group at National Aerospace Laboratories, Bangalore since Dec 1996. His research interests are in the area of visuals for flight simulation and synthetic vision.

Towards Vision Fusion for Integrated Enhanced Vision System

VPS Naidu[+] and Girija Gopalratnam
Scientists, Multi Sensor Data Fusion Lab

Flight Mechanics and Control Division,

National Aerospace Laboratories, Bangalore, India

Integrated Enhanced Vision System (IEVS) combines the features of Sensor Vision (SV), Synthetic Vision Systems (SVS) and aircraft status from navigation sensors. IEVS is expected to reduce the pilot workload by providing a better situation awareness through a head up display of the surrounding areas especially during takeoff/landing in adverse weather conditions.

The core part of the IEVS is the "Vision Fusion" which involves fusion of imagery from several sensor sources utilizing the most informative aspects of each of the component sensors. To properly perform fusion, it is essential to ensure that the information from each sensor refers to the same features in the environment. The different sensors of the IEVS would have different acquisition lattices and optics resulting in images having data structures that are substantially different from each other. Thus, the images must be registered before any fusion can be performed.

In this lecture the following aspects towards "Vision Fusion" will be covered:

- Image Registration through geometric correction based on a spatial transformation defined by user selected control points
- Pyramidal approach for computational cost reduction for registration and fusion
- Image fusion algorithms based on Principal Component Analysis, Spatial Frequency and Wavelets

The talk will also cover some of the aspects of the Multi-scale Retinex (MSR) algorithm [1]. MSR algorithm is being considered as a potential general-purpose image enhancement/fusion algorithm for producing good visual representations of scenes in IEVS.

[1] Glenn Hines, Zia-ur Rahman, Daniel Jobson and Glenn Woodell, "Multi-Image Registration for an Enhanced Vision System", Proceedings of the SPIE, vol. 5108, pp. 231-241, 2003.

Towards Vision Fusion for Integrated Enhanced Vision System

VPS Naidu
Multi Sensor Data Fusion Lab
Flight Mechanics and Control Division
National Aerospace Laboratories
Bangalore-17, India
vpsnaidu@csir.res.in

Overview of Presentation

- Introduction
- Image Registration
- Image Pyramids
- Image Fusion
- Retinex

Integrated Enhanced Vision System

Vision Sensors
- LWIR
- SWIR
- CCD

Ad: obstacle detection
no reference system
no database necessary
Dis: difficult image interpretation

raw data

Vision Processing
- Remapping
- Restoration
- Segmentation
- Object extraction

parameters

HMI system input
- Control input

Synthetic Vision
- Terrain Model
- Model projection

synthetic image

Vision Fusion

Terrain object identification

Obstacle identification

In compatibilities between sensed and terrain data can be used for obstacle detection

fused image

Data Fusion

Obstacle detection

Traffic Situation

Conflict prediction

position/attitude/heading

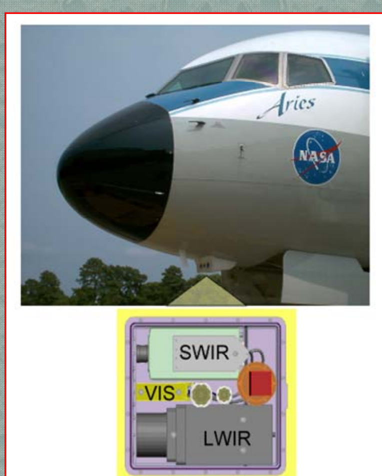
Navigation sensors
- INS
- GPS
- Air data
- other

Disadvantages of synthetic vision and vision sensors cancel out each other

Critical tasks in civil aviation are landing approaches and taxing, especially under adverse weather conditions, enhanced vision system play an important role within pilot assistance systems

HMI-Display system
- HUD
- HDD

EVS pod mounted forward-looking underneath the NASA Aries 757



	SWIR	LWIR	CCD
Image dimensions	320Hx240V	320Hx240V	542Hx497V
Optics FOV	34^0Hx25^0V	39^0Hx29^0V	34^0Hx25^0V
Frame rate	60Hz	60Hz	30Hz

LWIR SWIR CCD

Ref: Glenn D. Hines etal., "Real-time enhanced vision system"

Primary flight display with pathway guidance

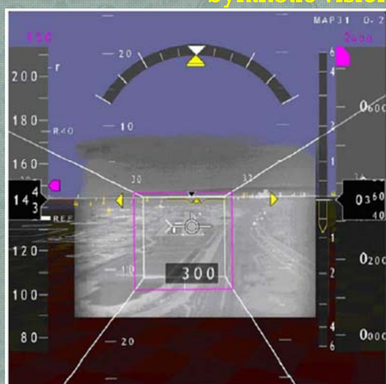
Widely used navigation concept in synthetic vision systems is tunnel-in-the-sky type

A series of boxes is displayed in 3D space, extending along the planned track of a/c

Pilot's task is to fly the a/c through these boxes to stay on track laterally and vertically

It could be a tool for very accurate hand flown approaches and reducing pilot's workload during the busy approach phase of the flight

Synthetic vision display with enhanced vision overlay



Overlaying enhanced view on top of synthetic view and letting the pilot control the degree of opacity of the enhanced image, an integrity check can be performed by the pilot

Benefits: Pilot has to deal with only one system instead of many

He must familiarize himself with only one user interface

All relevant information is presented to him in a consistent form, leading to an increased situation awareness

System has the capacity of highlighting important information and filtering unnecessary data based on current situation contest

Ref: Peter Lundknist, "Potential application .....air port", School of Aviation, Lund University, 2006

Image Registration

Image registration is the process of overlaying two or more images of the same scene taken at different times, from different view points and/or different sensors

Geometrically aligns two images – the reference and sensed images

Image registration is a crucial step in all image analysis tasks in which the final information is gained from the combination of various data sources

What is Geometric Transformation ?

Modify the positions of pixels in a image

- To create special effects
- To register two images taken from the same scene at different time
- To morph one image to another

How to define a geometric transformation ?

Let $f(u,v)$ denote the original image and $g(x,y)$ the deformed image, then these are related as:

Forward mapping : $g(x,y) = f(u(x,y), v(x,y))$

inverse mapping : $f(u,v) = g(x(u,v), y(u,v))$

Geometric Transformation - refers to a combination of translation, scaling and rotation, with the following form

$$\mathbf{x} = \mathbf{RS}(\mathbf{u} - \mathbf{t}) \qquad \mathbf{u} = (\mathbf{RS})^{-1}(\mathbf{x} - \mathbf{RSt})$$

Note: interchanging the order of operations may lead to different results

Polynomial Warping – it includes all deformations that can be modeled by polynomial transformations

Polynomial transform of Nth degree is : $x = \sum_{i=0}^{N} \sum_{j=0}^{N} a_{ij} u^i v^j \qquad y = \sum_{i=0}^{N} \sum_{j=0}^{N} b_{ij} u^i v^j$

Note: all possible geometric transformations are special cases of the affine mapping that has only first order terms

$$x = a_{00} + a_{10}u + a_{01}v$$
$$y = b_{00} + b_{10}u + b_{01}v$$

In matrix notation: $\begin{bmatrix} x_0 & y_0 \\ x_1 & y_1 \\ x_2 & y_2 \end{bmatrix} = \begin{bmatrix} u_0 & v_0 & 1 \\ u_1 & v_1 & 1 \\ u_2 & v_2 & 1 \end{bmatrix} \begin{bmatrix} a_{10} & b_{10} \\ a_{01} & b_{01} \\ a_{00} & b_{00} \end{bmatrix}$

Image Registration Methods

Its applications can be divided into four main groups according to the manner of the image acquisition:

Different view points (multiview analysis):

images of the same scene are acquired from different view points

aim is to gain larger area or 3D view of the scanned scene

Different times (multitemporal analysis):

images of the same scene are acquired at different times

aim is to fine and evaluate changes in the scene

Different sensors (multimodel analysis):

images of same scene are acquired by different sensors

aim is to integrate the information to gain more complex and detailed scene representation

Scene to model registration :

images of scene and a model of the scene are registered

model can be a computer representation of the scene (digital elevation models)

aim is to localize the acquired image in the scene

Steps in Image Registration

Due to the diversity of images to be registered and due to various types of degradation, it is impossible to design a universal method applicable to all registration tasks

Feature Detection: Salient and distinctive objects

Features can be represented by their point representatives

Feature Matching: Correspondence between the features to be established

Feature descriptors and similarity measures

Transform Model Estimation: Parameters of mapping functions

Image re-sampling and transformation: Transform sensed image by mapping function

Compute image values in non-integer coordinates

Image Registration Method

Assume the mapping function is a polynomial of order N

step1: identify $K > N$ corresponding (control) points between two images i.e.

$$(u_i, v_i) \leftrightarrow (x_i, y_i, 1) \qquad i = 1,2,\ldots,K$$

step2: determine the coefficients $a_i, b_i \quad i = 1,\ldots,N-1$ by solving

$$a_{00} + a_{10}u_i + a_{01}v_i + \ldots = x_i$$

$$b_{00} + b_{10}u_i + b_{01}v_i + \ldots = y_i \quad i = 1,2,\ldots,K$$

$$\mathbf{Aa} = \mathbf{x} \qquad \mathbf{Ab} = \mathbf{y}$$

the solution is:

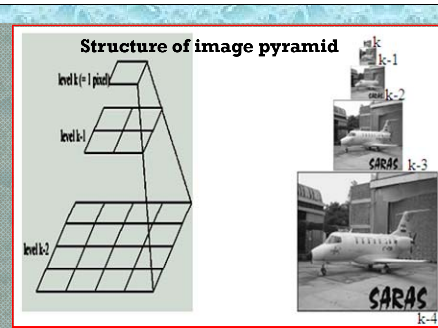
$$\mathbf{a} = (\mathbf{A}^T\mathbf{A})^{-1}\mathbf{A}^T\mathbf{x} \qquad \mathbf{b} = (\mathbf{A}^T\mathbf{A})^{-1}\mathbf{A}^T\mathbf{y}$$

Image Pyramids

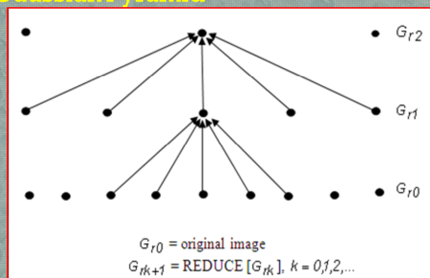
Strength of pyramid comes from the increase in processing speed on the image operations

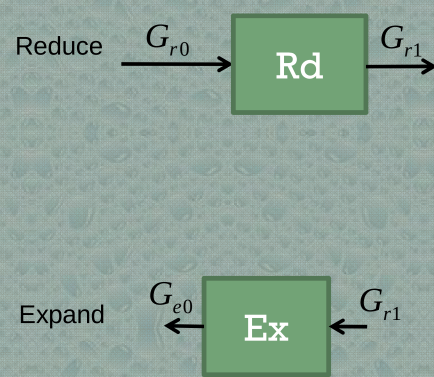
It permits to work at coarser resolutions where there are less pixels to be processed

Each level of pyramid is ¼ smaller than preceding level



Gaussian Pyramid





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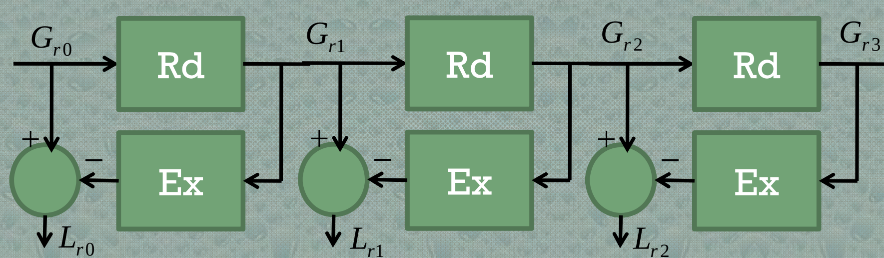
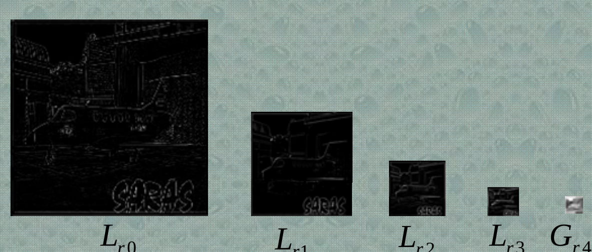
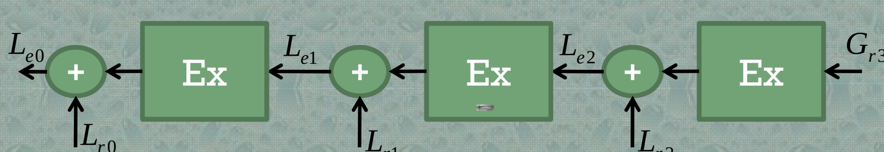
Laplacian Pyramid







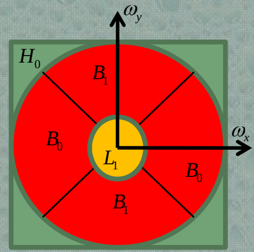
vpsnaidu@csir.res.in

Steerable Pyramid

Image is subdivided into a collection of sub-bands localized in scale and orientation

Sub-bands are translation- and rotation-invariant

Decomposition is best define in Fourier domain, where the sub-bands are polar-separable

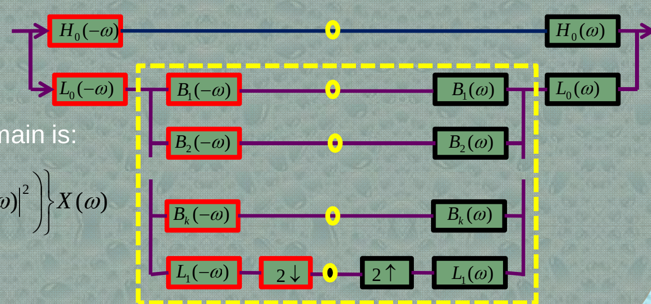


Single-stage first derivate (i.e. two orientation band) steerable pyramid transform

$\{B_k(\omega) \mid k = 0,1\}$ Band-pass oriented filters

$H_0(\omega)$ Non-oriented high pass filter

$L_1(\omega)$ Narrowband low pass filter



Single stage of steerable pyramid

Reconstructed image in frequency domain is:

$$\hat{X}(\omega) = \left\{ |H_0(\omega)|^2 + |L_0(\omega)|^2 \left(|L_1(\omega)|^2 + \sum_{k=0}^{n} |B_k(\omega)|^2 \right) \right\} X(\omega)$$

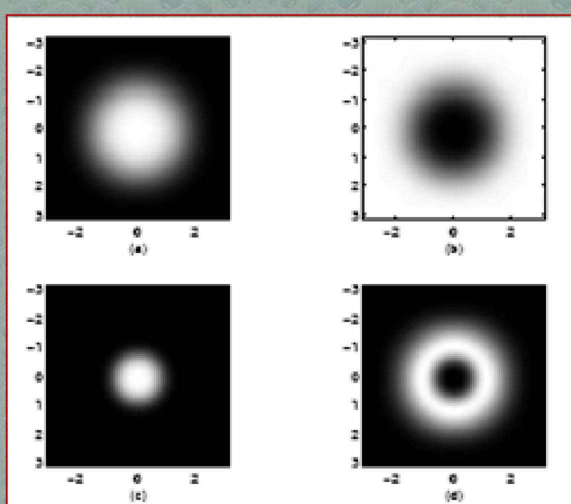
Perfect Reconstruction Constraints

Unity system response amplitude: $|H_0(\omega)|^2 + |L_0(\omega)|^2 \left(|L_1(\omega)|^2 + \sum_{k=0}^{n} |B_k(\omega)|^2 \right) = 1$

Recursion relationship: LP branch of the diagram must be unaffected by insertion of the recursive portion of the system

$$|L_1(\omega/2)|^2 \left(|L_1(\omega)|^2 + \sum_{k=0}^{n} |B_k(\omega)|^2 \right) = |L_1(\omega/2)|^2$$

Aliasing cancellation (for a circular symmetric filter): $L_1(\omega) = 0, \quad |\omega| > 0.5\pi$



Fourier spectra of a set of zeroth derivative steerable pyramid filter over the range $[-\pi,\pi]\mathrm{x}[-\pi,\pi]$

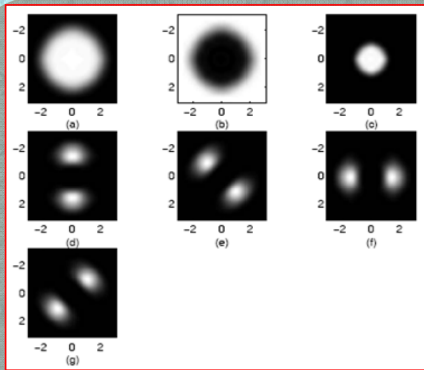
a) Low pass filter $L_0(\omega)$

b) high pass filter $H_0(\omega)$

c) Low pass filter $L_1(\omega)$

d) Band pass filter $L_0(\omega)B_0(\omega)$

Ref: Anestis Karararidis and Eero Simoncelli, " A filter design .....pyramid image transforms", Proc. ICASSP-96, may 7-10, Atlanta, GA



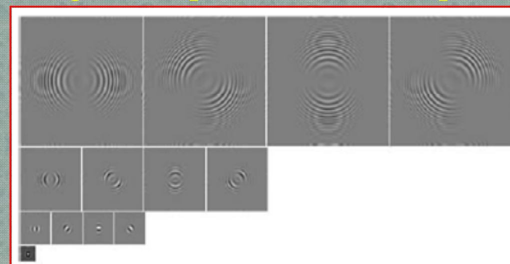
Fourier spectra of a set of third derivative steerable pyramid filter over the range $[-\pi,\pi]\mathrm{x}[-\pi,\pi]$

a) Low pass filter $L_0(\omega)$ b) high pass filter $H_0(\omega)$

c) Low pass filter $L_1(\omega)$

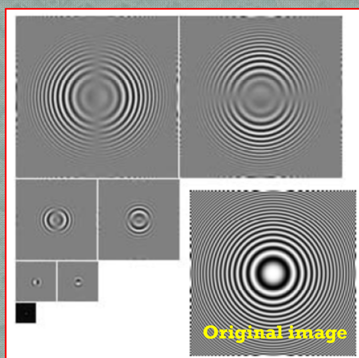
d-g) Band pass filters $L_0(\omega)B_0(\omega)$

Image decomposition of the zone-plate



Using third derivate steerable pyramid filters

Four orientation bands & three different scales



Using first derivate steerable pyramid filters

Two orientation bands & three different scales

Ref: Anestis Karararidis and Eero Simoncelli, " A filter design .....pyramid image transforms", Proc. ICASSP-96, may 7-10, Atlanta, GA

performance evaluation of Gaussian, Laplacian and Steerable pyramids

Metrics	Gaussian pyramid				Laplacian pyramid				Steerable pyramid			
	L1	L2	L3	L4	L1	L2	L3	L4	L1	L2	L3	L4
RMSE	10.62	21.08	30.20	36.80	**0**	**0**	**0**	1.34e-014	3.09e-004	3.09e-004	3.09e-004	3.09e-004
PFE	7.54	14.97	21.44	26.12	**0**	**0**	**0**	9.53e-015	2.20e-004	2.20e-004	2.20e-004	2.20e-004
MAE	5.83	12.07	18.74	24.97	**0**	**0**	**0**	7.19e-015	2.25e-004	2.25e-004	2.25e-004	2.25e-004
CORR	0.99	0.99	0.98	0.96	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
SNR	22.46	16.50	13.38	11.66	**inf**	**inf**	**Inf**	320.42	111.17	111.17	111.17	111.17
PSNR	37.91	34.93	33.36	33.51	**inf**	**inf**	**Inf**	186.89	83.26	83.26	83.26	83.26
MI	1.27	1.19	1.13	1.09	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**

Root mean square error by adding different levels of noise

Noise Var.	Gaussian pyramid				Laplacian pyramid				Steerable pyramid			
	L1	**L2**	**L3**	**L4**	**L1**	**L2**	**L3**	**L4**	**L1**	**L2**	**L3**	**L4**
0	10.62	21.08	30.20	36.80	**0**	**0**	**0**	**0**	0.0003	0.0003	0.0003	0.0003
0.001	10.75	21.11	30.21	36.80	**8.06**	**8.06**	**8.06**	**8.06**	**8.06**	**8.06**	**8.06**	**8.06**
0.005	**11.32**	21.23	30.27	36.83	17.71	17.71	17.71	17.71	17.71	17.71	17.71	17.71
0.01	**11.96**	**21.42**	**30.36**	**36.90**	24.76	24.76	24.76	24.76	24.76	24.76	24.76	24.76
0.05	**16.78**	**23.26**	**31.37**	**37.60**	51.82	51.82	51.82	51.82	51.82	51.82	51.82	51.82
0.1	**21.22**	**25.50**	**32.75**	**38.66**	67.97	67.97	67.97	67.97	67.97	67.97	67.97	67.97
0.5	**37.56**	**37.17**	**40.78**	**44.54**	103.45	103.45	103.45	103.45	103.45	103.45	103.45	103.45

Pixel Level Image Fusion

Principal Component Analysis (PCA):

Organize the data of images to be fused into column vectors and subtract the empirical mean from each column and let the resulting matrix is X

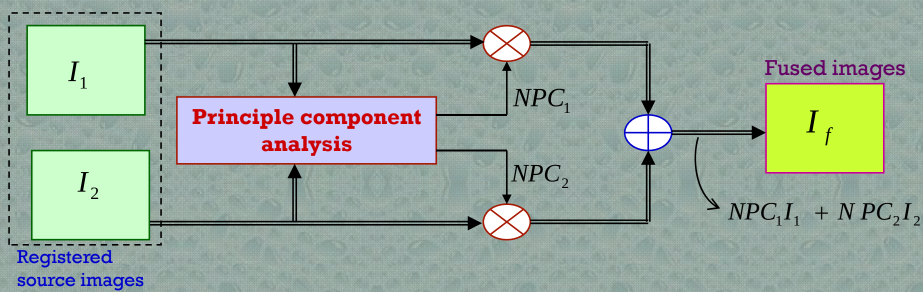
Compute the covariance matrix $C = X^T X$

Compute the eigenvectors V and eigenvalue D of and sort them by decreasing eigenvalue

Both V and D are of dimension $2\text{x}2$

Consider the first column of V which corresponds to larger eigenvalue to compute the principle components: $NPC_1 = \frac{V(1)}{\sum V}$ $NPC_2 = \frac{V(2)}{\sum V}$

PCA based weighted image fusion:



Spatial Frequency (SF)

Spatial frequency for a given image I of dimension MxN is defined as:

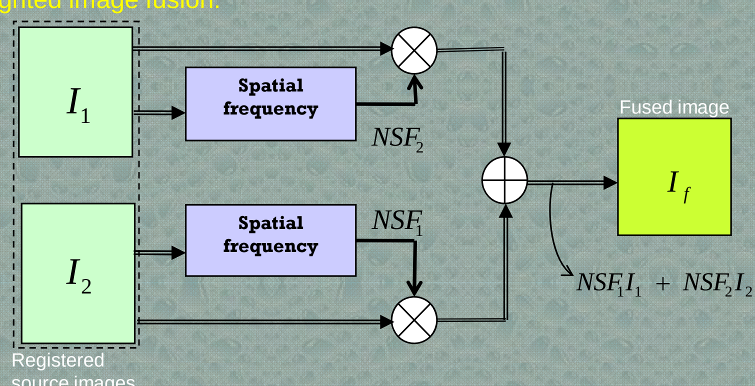
Row frequency: $RF = \sqrt{\frac{1}{MN}\sum_{i=0}^{M-1}\sum_{j=1}^{N-1}[I(i,j) - I(i,j-1)]^2}$

Column frequency: $CF = \sqrt{\frac{1}{MN}\sum_{j=0}^{N-1}\sum_{i=1}^{M-1}[I(i,j) - I(i-1,j)]^2}$

Spatial frequency: $SF = \sqrt{RF^2 + CF^2}$

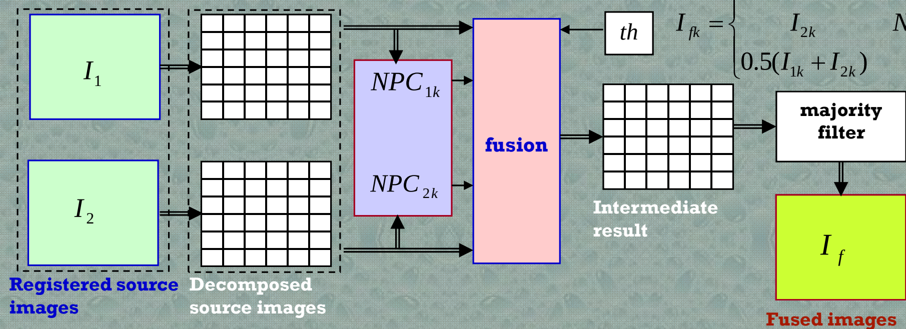
Computed spatial frequencies are then normalized as: $NSF_1 = \frac{SF_1}{SF_1 + SF_2}$ & $NSF_2 = \frac{SF_2}{SF_1 + SF_2}$

SFA based weighted image fusion:



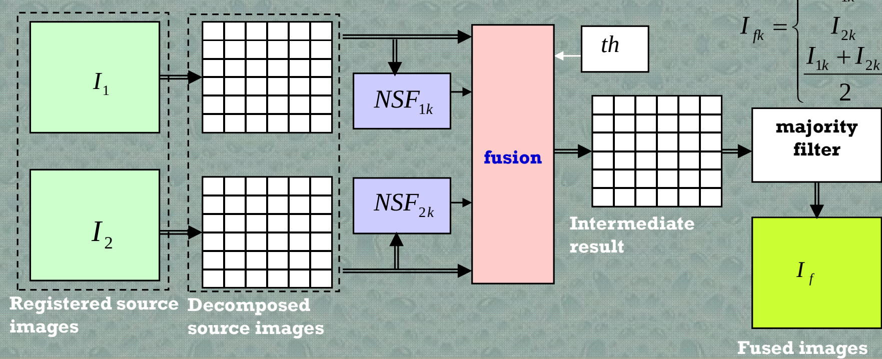
PCA based block image fusion: input images are decomposed into blocks (I_{1k} & I_{2k})

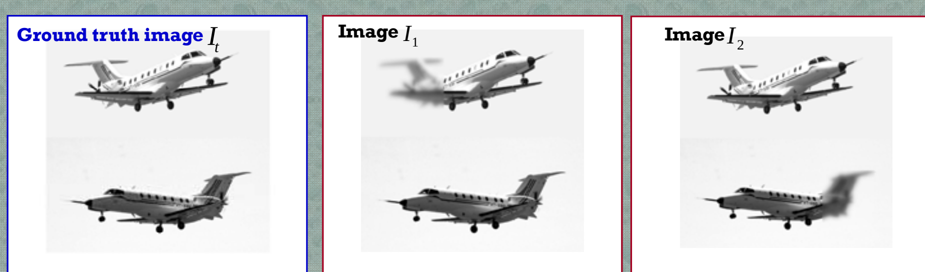
$$I_{fk} = \begin{cases} I_{1k} & NPC_{1k} > NPC_{2k} + th \\ I_{2k} & NPC_{1k} < NPC_{2k} - th \\ 0.5(I_{1k} + I_{2k}) & \text{otherwise} \end{cases}$$



SF based block image fusion:

$$I_{fk} = \begin{cases} I_{1k} & NSF_{1k} > NSF_{2k} + th \\ I_{2k} & NSF_{1k} < NSF_{2k} - th \\ \dfrac{I_{1k} + I_{2k}}{2} & \text{otherwise} \end{cases}$$





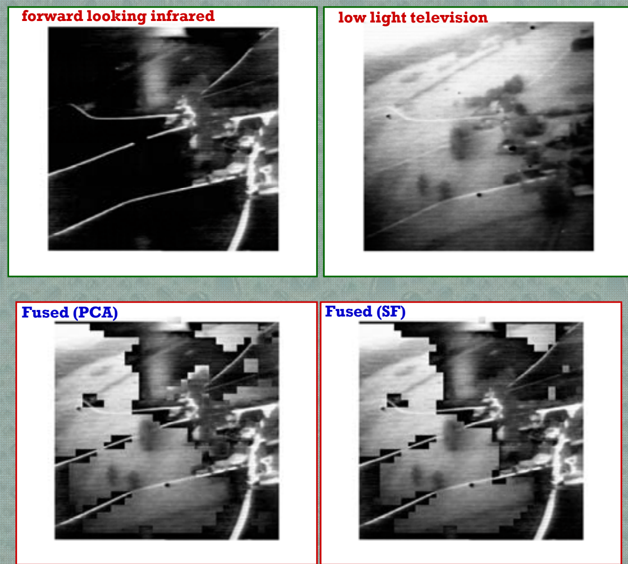
first architecture

second architecture

Block size of 64x64 and $th = 0.025$

		RMSE	PFE	PSNR	SD	SF
Architecture-I	PCA	5.8056	2.5388	40.5264	55.7286	16.7602
	SF	5.7927	2.5332	40.5360	55.7302	16.7636
Architecture-II	PCA	0.1669	0.073	55.9395	57.0859	18.8962
	SF	0.161	0.0704	56.0964	57.086	18.8963

Fusion of Dissimilar Sensors



Block size of 16x16 and $th = 0.01$

	H_e	SD	CE	MI
PCA	7.88	74.79	0.59	2.63
SF	7.83	76	0.53	2.67

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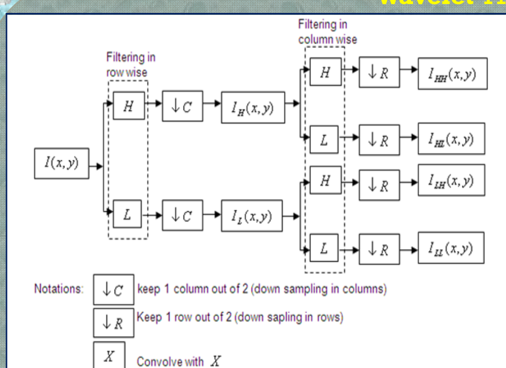
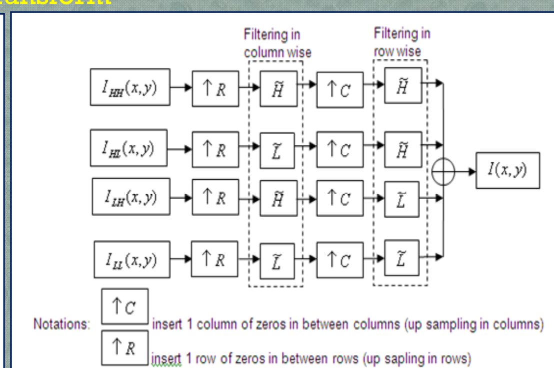
Wavelet Transform





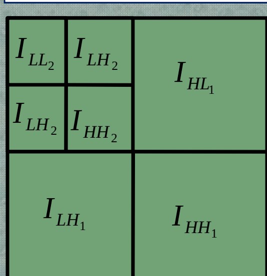
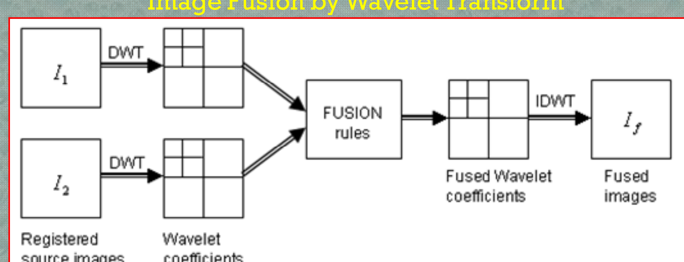


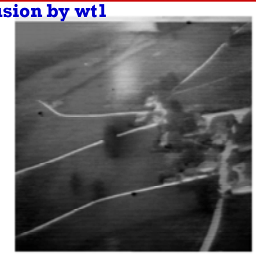
Image Fusion by Wavelet Transform



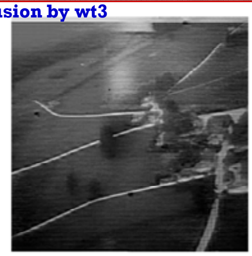
fused image: $I_f(x,y) = IDWT[\phi\{DWT(I_1(x,y)), DWT(I_2(x,y))\}]$

The fusion rule ϕ used in this study is simply averages the approximation coefficients and picks the detailed coefficient in each sub band with the largest magnitude

Fusion by wt1

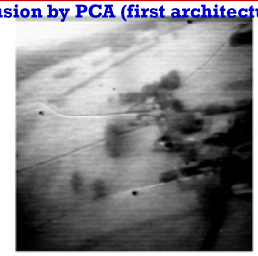


Fusion by wt3



Fusion by wt5

Fusion by PCA (first architecture)



Fusion by SF (first architecture)

	H_e	SD	CE	MI
PCA	7.87	96.47	2.64	2.44
SF	7.33	47.47	2.19	2.27
wt1	7.3	47.83	4.38	2.19
wt2	7.19	48.56	5.03	2.18
wt3	6.96	50.29	5.71	2.16
wt4	6.84	54.49	5.84	2.15
wt5	6.91	58.30	5.77	2.14

Observation:

SD showed that PCA is better but by observing the fused image it is not

It may be due to the consideration of contrast in SD calculations

It is observed that wavelets with higher level of decomposition show better results

Retinex Image Enhancement Techniques

- Why called Retinex?
  - An method bridging the gap between images and the human observation of scenes
- Origin of Retinex (retina + cortex)
  - Proposed by Edwin Land[1] in 1986
  - A model of lightness and color perception of human vision
- No theoretical but experimentally proved Retinex
  - An automatic imaging process
  - Independent of variations in the scene
- Depending on the circumstances, Retinex could achieve

Sharpening: Compensation for the blurring introduced by image formation process

Color constancy processing: Improve consistency of output as illumination changes

Dynamic range compression

Single Scale Retinex (SSR)

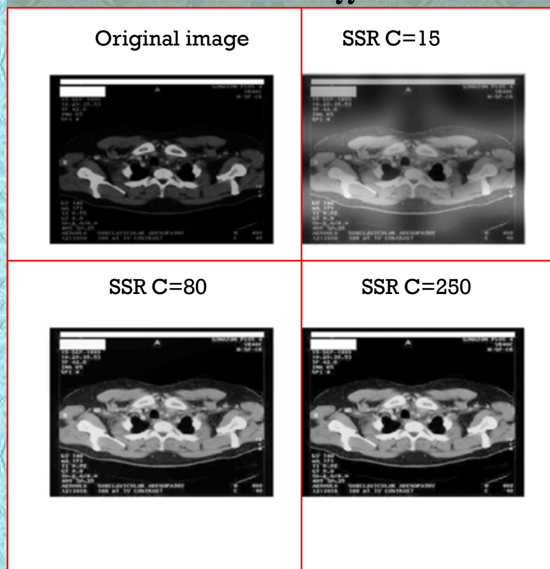
$$R(x,y) = \log I(x,y) - \log[F(x,y) \otimes I(x,y)]$$

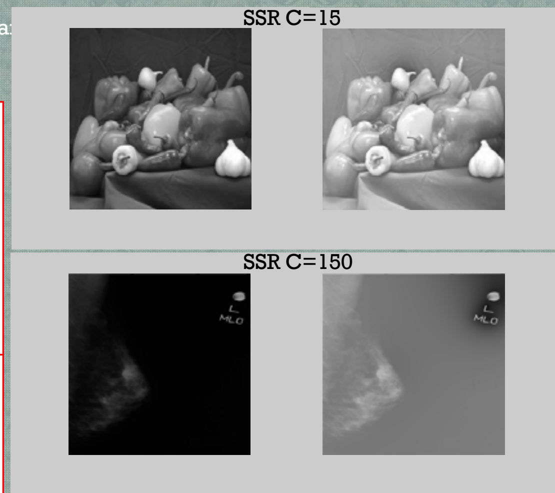
where $R(x,y)$: Retinex output $\quad F(x,y) = ke^{-(x^2+y^2)/c^2}$: Surrounding function

$I(x,y)$: Image intensity

c : Gaussian shaped surrounding space consta

k : is selected such that $\iint F(x,y)\,dxdy = 1$





Small scale (small c):
good dynamic range compression

large scale (large c):
good tonal rendition

Multi Scale Retinex (SSR)

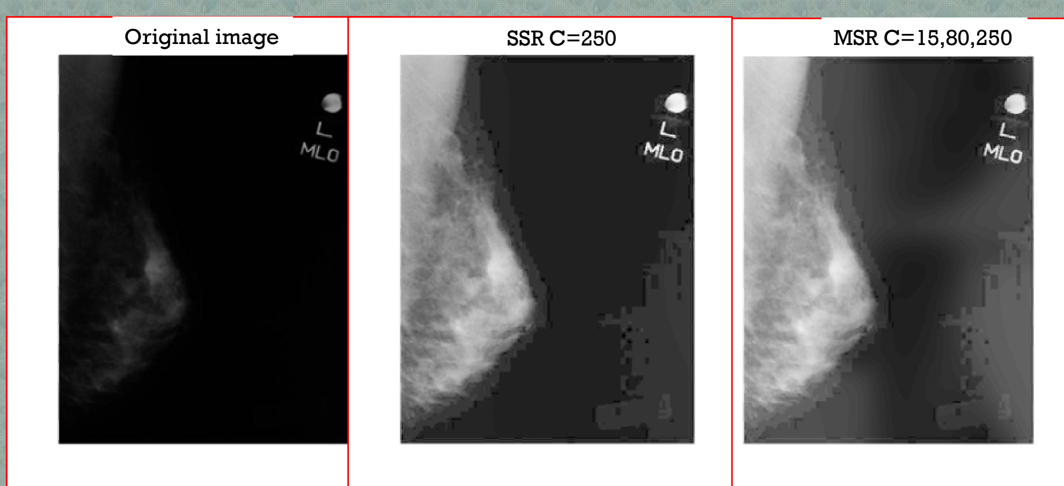
$$R(x,y) = \sum_{n=1}^{N} w_n \{\log I(x,y) - \log[F_n(x,y) \otimes I(x,y)]\}$$

N : number of scales

w_n : weight associated with the nth scale

Empirical values: $N = 3,\ w_n = \frac{1}{3}$

$c = 15, 80\ \&\ 250$: comparatively for each scale in Fn



MSR is better than SSR in balance of dynamic compression and color rendition

Multi Sensor Fusion and Enhancement

RGB to GS transform:

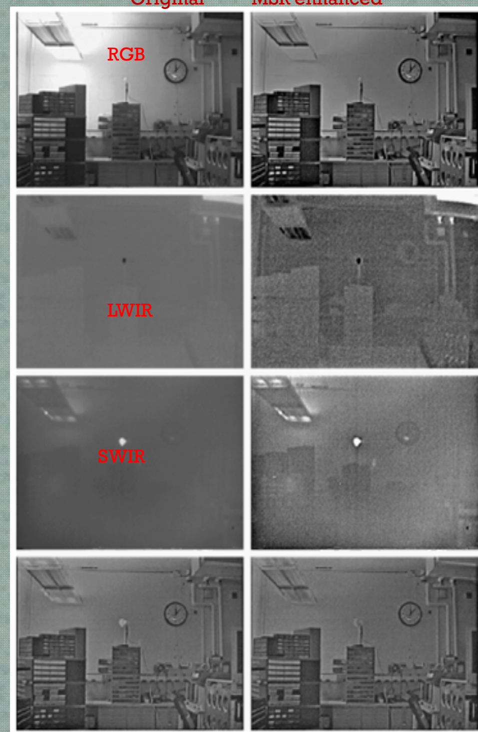
$$GS = 0.299R + 0.587G + 0.114B$$

$$I_F = 0.299SWIR + 0.587LWIR + 0.114GS$$

Left : $I_F = 0.299LWIR + 0.587GS + 0.114SWIR$

Right: $I_F = 0.299SWIR + 0.587GS + 0.114LWIR$

Original MSR enhanced



Fused images provide information than any of the three bands can individually

Compactness of the fused data, one instead of three, also makes it more practical for pilot in terms of ease of viewing and interpretation

Ref: Zia-ur Rahaman et. Al., "Multi-sensor fusion and ……enhancement algorithms

Conclusion

- IEVS architecture
- Multi-model Image Registration
- Image Pyramids
- Pixel-Level Image Fusion
- Retinex

Speaker Profile

VPS Naidu was born in Andhra Pradesh. He obtained Diploma in ECE from SV Govt. Polytechnic Tirupati, B.Tech in ECE from VR Sidhartha Engineering College Vijayawada and M.E. in Medical Electronics from Anna University Chennai in 1997. He is working at National Aerospace Laboratories, Bangalore as Scientist since December 2001. His areas of interest are: image registration, tracking and fusion.

Laboratory, Simulator and Flight Test Components in ESVS Development

Ronald V Kruk, Chief Scientist, CAE Inc., CANADA

In 1995 CAE began development of an Enhanced Synthetic Vision System (ESVS) which displayed a visual scene to the pilot incorporating three separate image sources: 1. a synthetic computer-generated terrain image; 2. an enhanced visual image from an electro-optical sensor (fused as an inset in the display); and 3. aircraft instrument symbology, all displayed on a Helmet Mounted Display (HMD). The laboratory test program evaluated issues critical in development of an ESVS designed to support autonomous all weather SAR operations down to 100 Ft. AGL in remote locations. A significant body of scientific and technical knowledge was generated, particularly with respect to human demand characteristics for scene content, texture, temporal parameters, conformal image content and fusion, as well as evaluation of the effects of a wide range of system limitations/errors. ESVS Flight Test began early in the program with component and concept testing. Particular emphasis was placed upon development of methodology relevant to the requirements and environment of the operational application of the system. Operational scenarios were developed and tested in the simulator, and later flown with the integrated ESVS in the National Research Council of Canada (NRC) B205.

Since 2003 the focus has been upon developing an Augmented Visionics System (AVS) as a solution to the Brownout/Whiteout problem. AVS scans the immediate surroundings of the aircraft with both passive Electro-Optical (EO) and Laser Imaging Detection and Ranging (LIDAR) sensors. The sensor data is fused with the content of a 3D synthetic database of the area the aircraft is flying over (The Common Environment and Common Database (CE/CDB), which applies a real-time translation and publishing process to small area updates through its storage structure and layered dataset design), and the result is displayed to the aircrew in real-time. The aircraft (and imagery) are registered to exact current location using the aircraft navigation systems

and the self-checking attributes of the change detection processing. Any differences between the original database (e.g. Due to inadequate resolution) and the terrain are corrected in real time, and obstacles not included in the original database are detected by the sensors, added to the database and portrayed as a geo-referenced 3D shapes - in sufficient detail to allow the aircrew to maneuver safely.

The penetration capabilities of the LIDAR through a wide range of obscurants have been tested in a purpose – designed facility at Canadian Forces Base (CFB) Valcartier, Canada. The scanning principles for the sensors and operation of the CE/CDB system in flight have been evaluated in flight test on board the NRC B412 research helicopter. More powerful, tighter beam dispersion lasers are being integrated for the next generation LIDAR and a multi-sensor EO array is in design. The next steps in building a fully operational system involve analysis and design based upon a specific air platform, in the context of a specific operational task and environment. We intend to apply a comprehensive evaluation in a Modeling and Simulation environment, as we did with the precursor ESVS program, culminating with validation in flight test.

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Laboratory, Simulator and Flight Test Components in ESVS Development

Ronald V. Kruk PhD.

Chief Scientist
CAE Inc.

NAL ESVS Workshop

Bangalore, 25 – 26 April 2008

CAE

Abstract

- In 1995 CAE began development of an ESVS which displayed an augmented visual scene to the pilot incorporating three separate image sources: 1. a synthetic computer - generated terrain image; 2. an enhanced visual image from an electro-optical sensor (fused as an inset in the display); and 3. aircraft instrument symbology, all displayed to the pilot on a Helmet Mounted Display (HMD). The ESVS laboratory test program evaluated issues critical in development of a hybrid Enhanced/Syntheti c system designed to support autonomous all weather SAR operations down to 100 Ft. AGL in remote locations. A significant body of scientific and technical knowledge was generated, particularly with respect to human demand characteristics for scene content, texture, temporal parameters, conformal image content and fusion, as well as evaluation of the effects of a wide range of system limitations/errors.ESVS Flight Test began early in the program with component and concept testing. Particular emphasis was placed upon development of methodology relevant to the requirements and environment of the operational application of the system. Operational scenarios were developed and tested in the simulator, and later flown with the integrated ESVS in the National Research Council of Canada (NRC) B205.
- Since 2003 the focus has been upon developing a solution to the Brownout/Whiteout problem: the "Augmented Visionics System" (AVS). AVS scans the immediate surroundings of the aircraft with both passive Electro-Optical (EO) and Laser Imaging Detection and Ranging (LIDAR) sensors. These sensors are complementary in terms of obscurant penetration, resolution and Field-of-Regard. The sensor data is fused with the content of a 3D synthetic database of the area the aircraft is flying over (The Common Environment and Common DataBase (CE/CDB), which applies a real-time translation and publishing process to small area updates through its storage structure and layered dataset design), and the result is displayed to the aircrew in Real - Time. The aircraft (and imagery) are registered to exact current location using the aircraft navigation systems (which may be augmented by an integral GPS/INS navigation package) and the self-checking attributes of the change detection processing. Any differences between the original database (e.g. Due to inadequate resolution) and the terrain are corrected in real time, and obstacles not included in the original database are detected by the sensors, added to the database and portrayed as a geo-referenced 3D shapes - in sufficient detail to allow the aircrew to maneuver safely.
- The penetration capabilities of the LIDAR through a wide range of obscurants have been tested in a purpose – designed facility at CFB Valcartier, Canada. The scanning principles for the sensors and operation of the CE/CDB system in flight have been evaluated in flight test on board the NRC B412 research helicopter. More powerful, tighter beam dispersion lasers are being integrated for the next generation LIDAR and a multi-sensor EO array is in design. The next steps in building a fully operational system involve analysis and design based upon a specific air platform, in the context of a specific operational task and environment. We intend to apply a comprehensive evaluation in a Modelling and Simulation environment, as we did with the precursor ESVS program, culminating with validation in flight test.

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Introduction

- Efforts to develop airborne Enhanced/Synthetic Vision Systems go back at least to the 1960s (USAF programs) and a major SVS development effort involving extensive ground and air tests of 2 Millimeter Wave Radar (MMWR) wavelength sensors and 2 IR wavelength sensors was conducted by the USAF, FAA, NASA and several universities in the early 1990s.

- In Canada, the effort began in 1995 within the Chief, Research and Development (AIR) sponsored Advanced Cockpit Technologies Program – A CMC/CAE scoping study in 1996 was followed by joint CRAD/SAR Directorate funding for a technology demonstration program.

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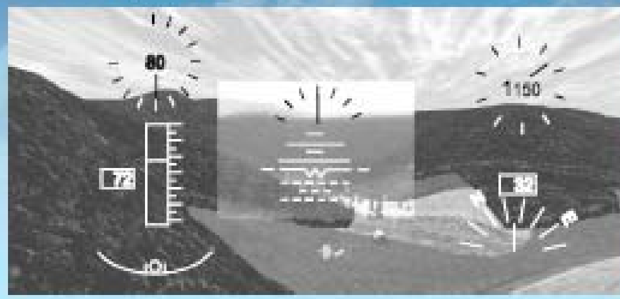
Operational Focus - Search and Rescue in Reduced Visibility Conditions

- Goal - **Operate down to 100 foot ceiling, 1/8 nautical mile visibility conditions and conduct critical mission task elements including:**
  - descent below local Minimum Descent Altitude in a search area without ground-based navigation support;
  - search for survivors, wreckage etc. in unknown terrain;
  - transition to and maintain hover during the conduct of a rescue operation; and
  - departure from the rescue area.

Design Concept: The Enhanced and Synthetic Vision System (ESVS)

- **Task:** Allow SAR pilots to perform a rescue mission in reduced visibility conditions.



- **Concept:** Create virtual Visual Meteorological Conditions that combine a clear terrain image with sensor information for obstacle detection.

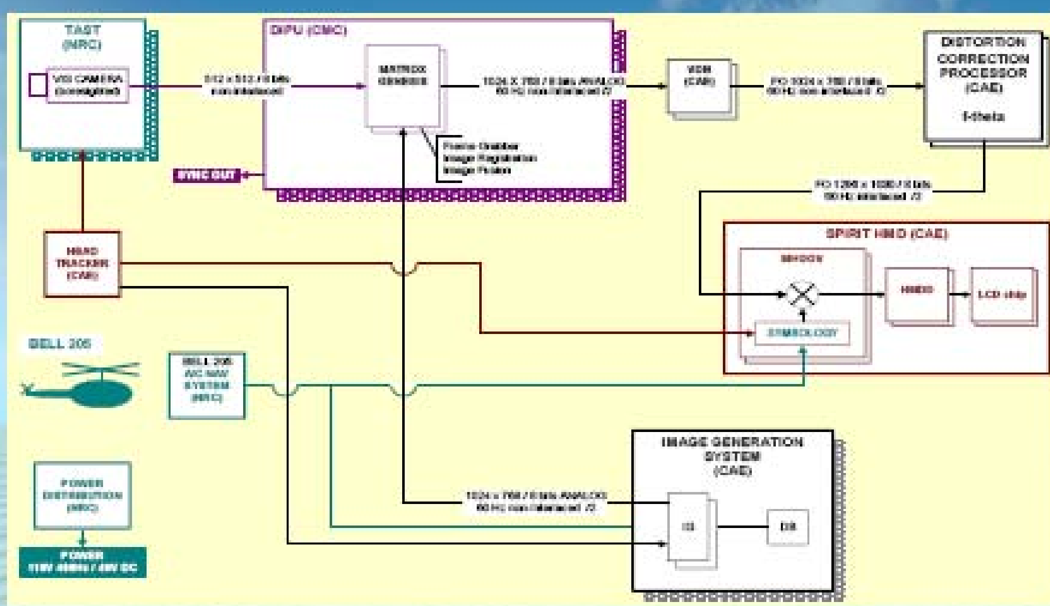
Design Concept for E/SVS

- E/SVS displayed an augmented visual scene to the pilot which incorporated three separate image sources:
  - a synthetic computer - generated terrain image;
  - an enhanced visual image from an electro-optical sensor (fused as an inset in the display); and
  - aircraft instrument symbology.
  - All information was displayed to the pilot on a Helmet Mounted Display (HMD).

E/SVS Operating Principles

- The synthetic image is used to maintain SA & navigate at altitudes where obstacles and terrain database limitations do not present a danger - at 300 ft decision height the sensor image becomes the primary reference.
- The sensor image is used at lower altitudes for obstacle detection, target acquisition and to register the synthetic image - at 100 ft decision height a transition to visual references takes place.
- The non-E/SVS pilot takes control to enter/maintain hover.

E/SVS Architecture




CAE
Development Approach
Front End Analysis
Laboratory Experiments
Simulator Studies
Flight Test
CAE AVS
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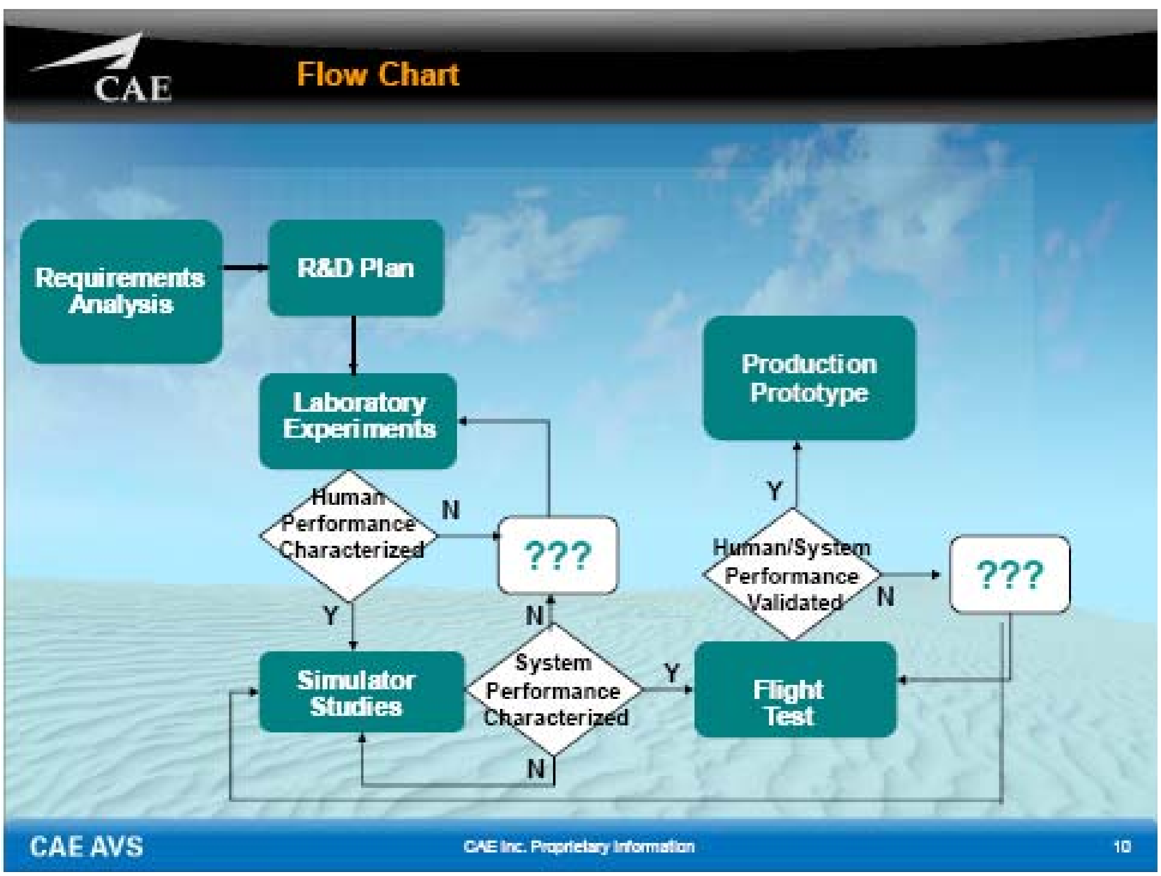
CAE
Flow Chart
Requirements Analysis
R&D Plan
Laboratory Experiments
Human Performance Characterized
N
Y
???
Simulator Studies
N
System Performance Characterized
Y
N
Flight Test
Production Prototype
Y
Human/System Performance Validated
N
???
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Front End Analysis

- Define Operational Requirements
- Determine Limits/Capabilities of Available Technology
- Define Functional Architecture for a Demonstration/ Prototype System
- Define R&D Plan - Specify Testing to be conducted in Laboratories, Simulators and Flight Test

Laboratory Experiments

- Apply current theory in Human Performance/Interface Requirements
- Evaluate novel approaches/algorithms in tightly controlled conditions
- ESVS Specifics - assess effects of: Latency, Stereo Vision, Terrain Texture, Symbology, Image Fusion Approaches, Sensor Characteristics

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Simulator Studies

- Fly scenarios too risky or expensive or difficult in the aircraft
- Assess the potential effects of component/full system configurations, limits of technology, environmental conditions.
- Develop and validate operational scenarios
- Apply results of laboratory experiments within the context of flying the intended platform in operational conditions, conducting the full range of operational tasks
- ESVS Specifics - evaluate effects of: Latency, Scene Content, Design Eyepoint, Control Laws, FOV, Stereo vision, Fused Display Insets, Navigation System Problems

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Flight Test

- Conduct component testing, evaluate fully integrated system
- Evaluate fundamental characteristics (Eg. Handling Qualities)
- Evaluate system performance in operational tasks (Onboard data collection system for objective performance evaluation)
- Validate simulator study results
- ESVS Specifics:
  - HQR with HMD optical variables, latencies, servosystem characteristics, interactions with Flight Control laws
  - Operational Test with navigation, search patterns, airfield approaches.

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E/SVS Research Program - Issues

Research Areas:

- quantification of the effects of system latencies on pilot performance;
- assessment of the effects of a sensor/synthetic design eye location which does not correspond to the location of the pilot's head;
- the determination of an effective field-of-view for the required tasks;
- an understanding of the effect of limited sensor platform roll motion on pilot behavior;
- analysis and selection of an appropriate image fusion technique;
- evaluation of scene content requirements to support the search and recovery phases of a SAR mission;
- the design of symbology sets to provide aircraft performance data and compensate for ESVS image limitations; and,
- comparison and validation of the UTIAS (simulator) and NRC (aircraft) facilities.

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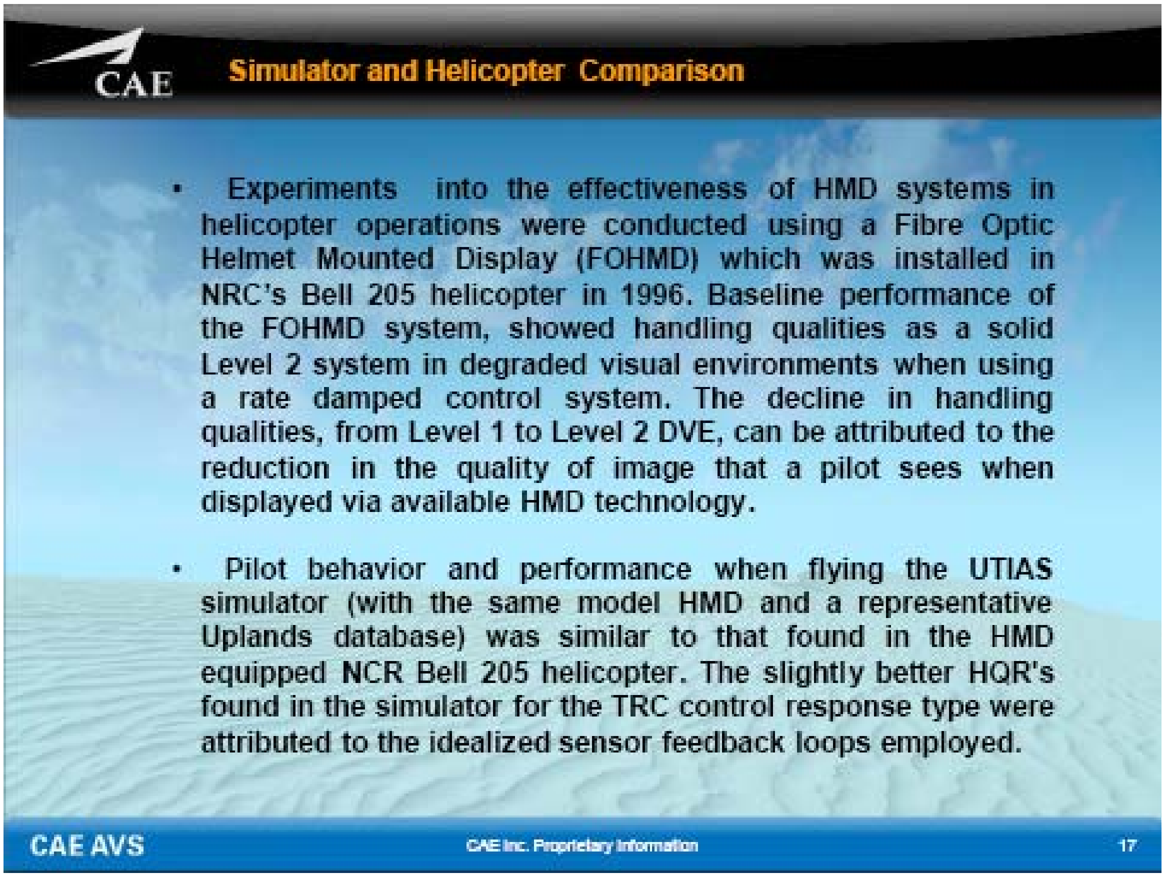
Mission Simulation

- Important aspects of the simulator studies at UTIAS included:
  - development of flight and control system models which emulated the NRC B205 aircraft, display and sensor systems;
  - an accurate visual database of the sites (Uplands Airport, Gatineau Hills) used in the flight trials of ESVS, development and evaluation of representative SAR mission scenarios; and,
  - development of performance assessment criteria which enabled valid comparison of system and pilot performance data from the UTIAS FFS and the NRC B205 aircraft.


CAE
Simulator and Helicopter Comparison
• Experiments into the effectiveness of HMD systems in helicopter operations were conducted using a Fibre Optic Helmet Mounted Display (FOHMD) which was installed in NRC's Bell 205 helicopter in 1996. Baseline performance of the FOHMD system, showed handling qualities as a solid Level 2 system in degraded visual environments when using a rate damped control system. The decline in handling qualities, from Level 1 to Level 2 DVE, can be attributed to the reduction in the quality of image that a pilot sees when displayed via available HMD technology.
• Pilot behavior and performance when flying the UTIAS simulator (with the same model HMD and a representative Uplands database) was similar to that found in the HMD equipped NCR Bell 205 helicopter. The slightly better HQR's found in the simulator for the TRC control response type were attributed to the idealized sensor feedback loops employed.
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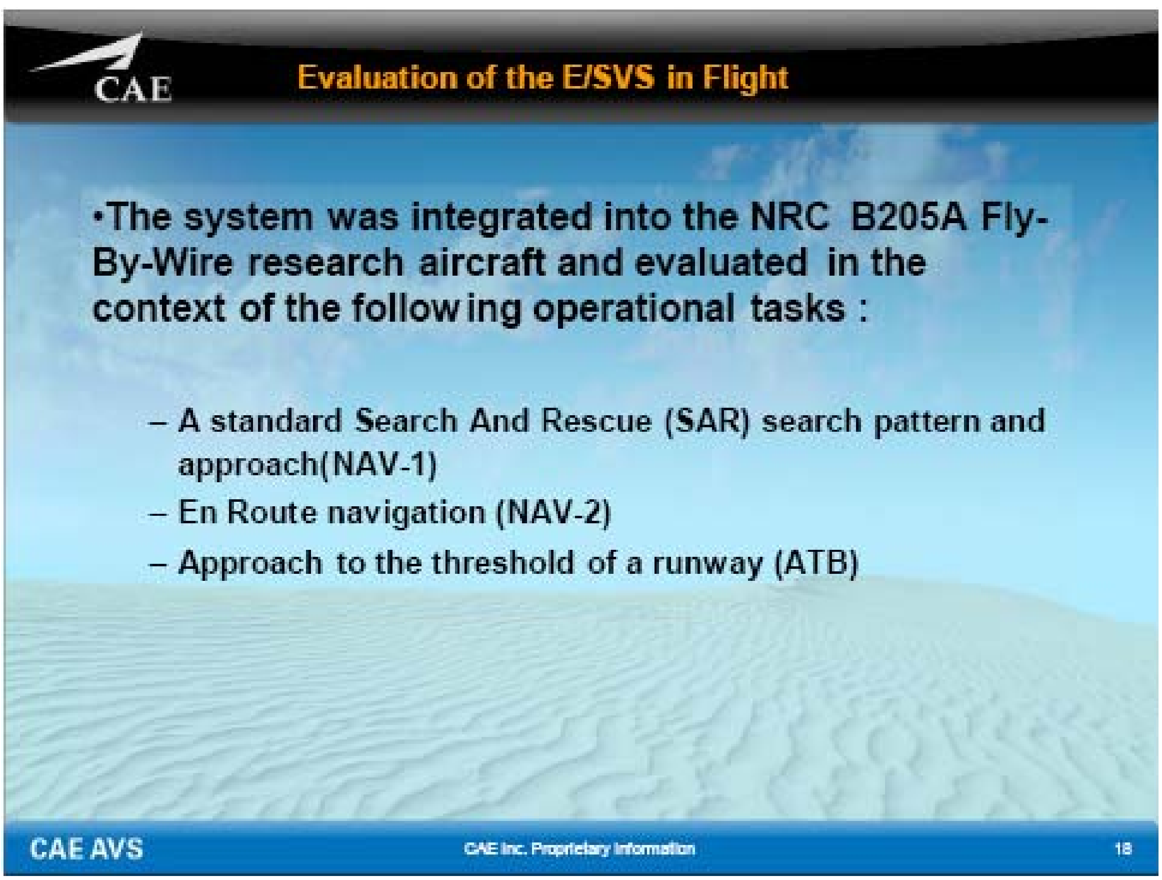
CAE
Evaluation of the E/SVS in Flight
•The system was integrated into the NRC B205A Fly-By-Wire research aircraft and evaluated in the context of the following operational tasks :
– A standard Search And Rescue (SAR) search pattern and approach(NAV-1)
– En Route navigation (NAV-2)
– Approach to the threshold of a runway (ATB)
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Evaluation of the E/SVS in Flight

- Procedure/Configuration was as follows :
  - A safety pilot monitored all flights.
  - Evaluation pilots flew an Attitude Command control system.
  - Pilots scanned the instrument panel below the E/SVS optics (Symbology was suppressed for these trials).
  - The HMD was equipped with an opaque visor (no see through).
  - Synthetic texture combined photo realistic and geometric elements.
  - The sensor image fusion algorithm was simple pixel averaging, with weights adjustable by evaluators.

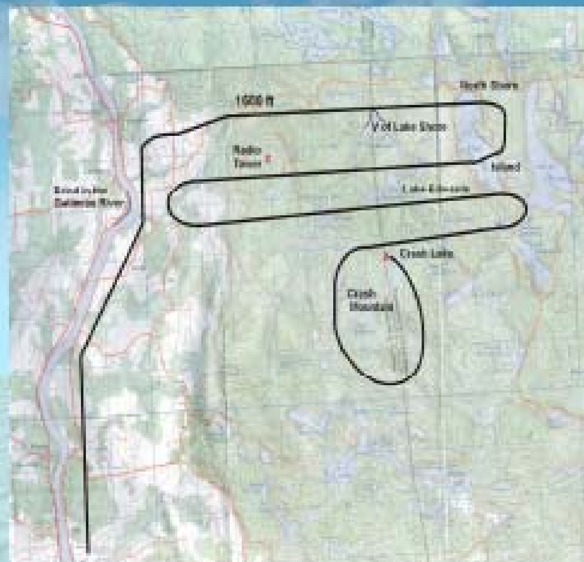
Evaluation of the ESVS in Flight - Sample Test Methodology - NAV-1

- Trial - "NAV 1" with 4 pilots.
  - Pilots had 3-4 hours of flying time with the system prior to data runs.
  - The evaluators flew a typical SAR pattern and had access to a topographic map of the route during the flight to aid their navigation.
  - The route was flown with the full ESVS (camera overlay at 100%), SVS only and clear-hood (baseline condition). Conditions were flown in the same flight so as to minimise environmental variability.
  - Objective data collected included DGPS altitude, latitude and longitude. Subjective comments were recorded in-flight and in a post-flight debriefing.

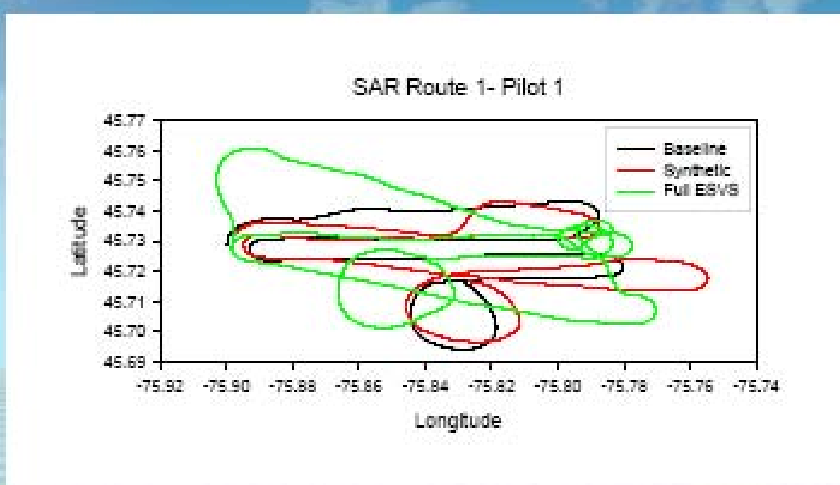
Evaluation of the ESVS - NAV 1 in - Flight Route

-Pilots flew a grid search pattern, as illustrated, in the Gatineau Hills region north of Ottawa.

-The route was flown at 1600ft ASL: height above ground varied between 50ft and 400ft.



Sample Results: GPS Track (Pilot 1)



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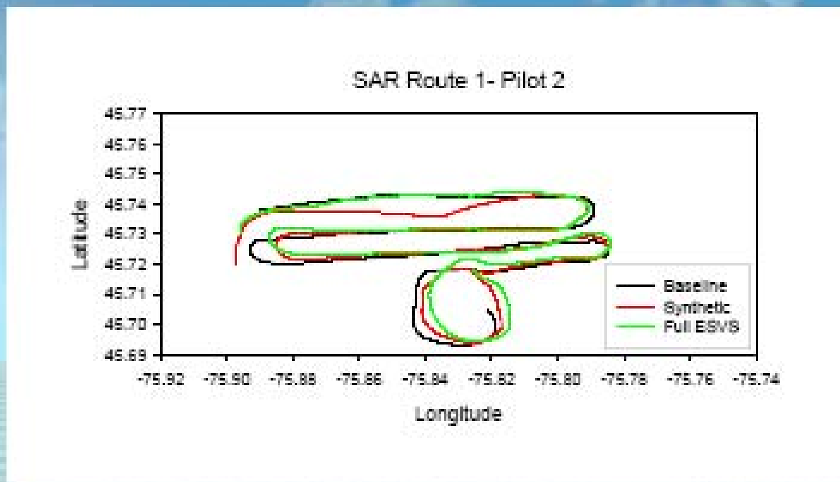
Sample Results: GPS Track (Pilot 2)



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Sample Results

- **Navigation results indicated that:**
  - The evaluation pilots were able to conduct the task with ESVS, however:
    - they had some difficulty in judging height;
    - they had difficulty in seeing distant objects in the sensor image.
  - Navigation performance with **SVS** only was better than E/SVS.
  - Visibility of some features (e.g., power lines) was better with **SVS** than with the full E/**SVS** or the naked eye.

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CAE — Live Video Frames of E/SVS (flight test 2001)

Flight Trials City

Flight Trials Nav

CAE — E/SVS Program Output

⌘E/SVS system development was a collaborative effort involving Canada's National Research Council (NRC) Flight Research Laboratory, CAE Inc., and Canadian Marconi Company as the core team.

•In addition to technology, the E/SVS program included a significant collaborative scientific research effort in government (Defense R&D Canada and academic (University of Toronto Institute for Aerospace Studies (UTIAS), McGill University, York University, Carlton University) laboratories:

– The E/SVS program generated: 2 PhD dissertations; 3 Masters theses; 11 technical reports; 19 scientific papers; many conference presentations.

•More than 80 hours of flight test w ere conducted on the integrated ESVS, ending in 2001.

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So what are we doing now?

- New technology has been developed with new partners(Neptec) and continuing the relationship with NRC for Flight Test.
- The goals of the application have changed.


CAE
The PROBLEM…..
End of transit
Top of the descent 200-500ft AGL
LZ identification
LZ reconnaissance
CAE AVS
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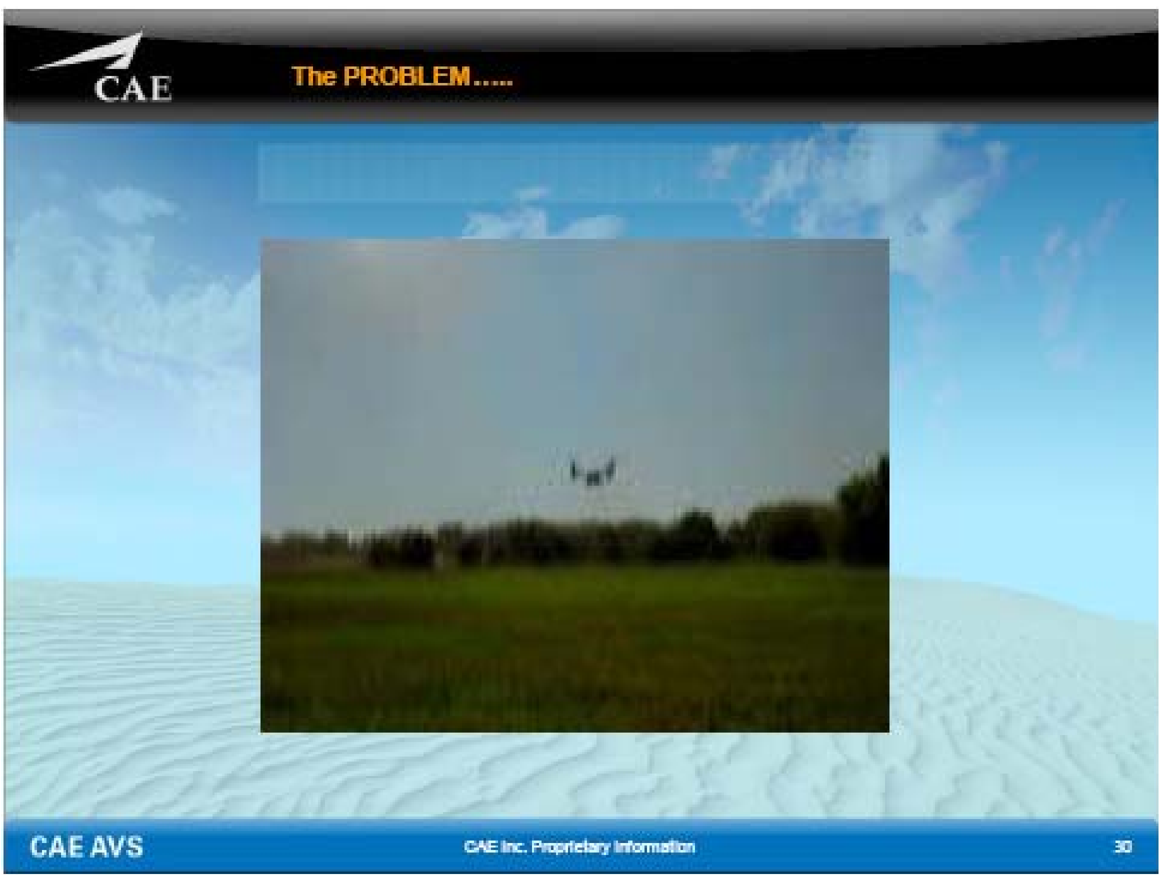
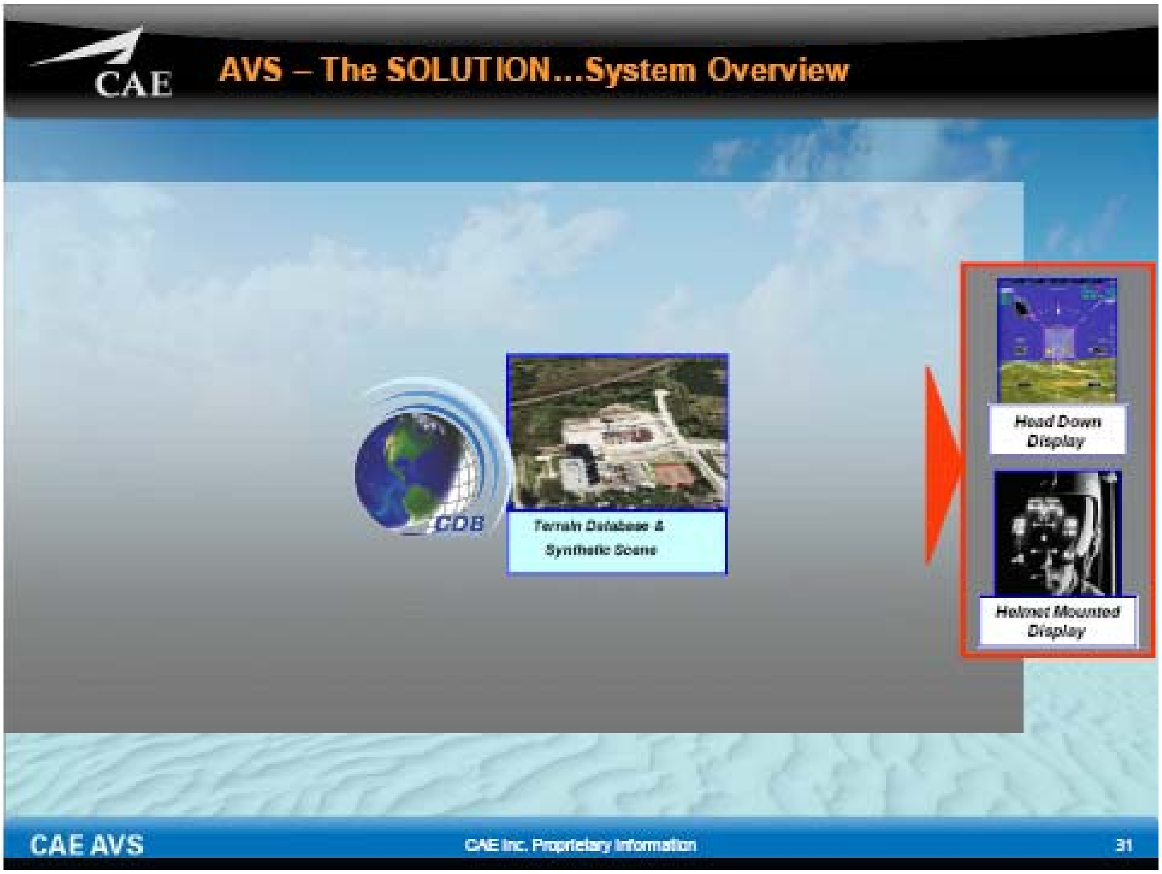

CAE
The PROBLEM…..
CAE AVS
CAE Inc. Proprietary Information
30



AVS – The SOLUTION…System Overview
CDB
Terrain Database &
Synthetic Scene
Head Down
Display
Helmet Mounted
Display
CAE AVS
CAE Inc. Proprietary Information
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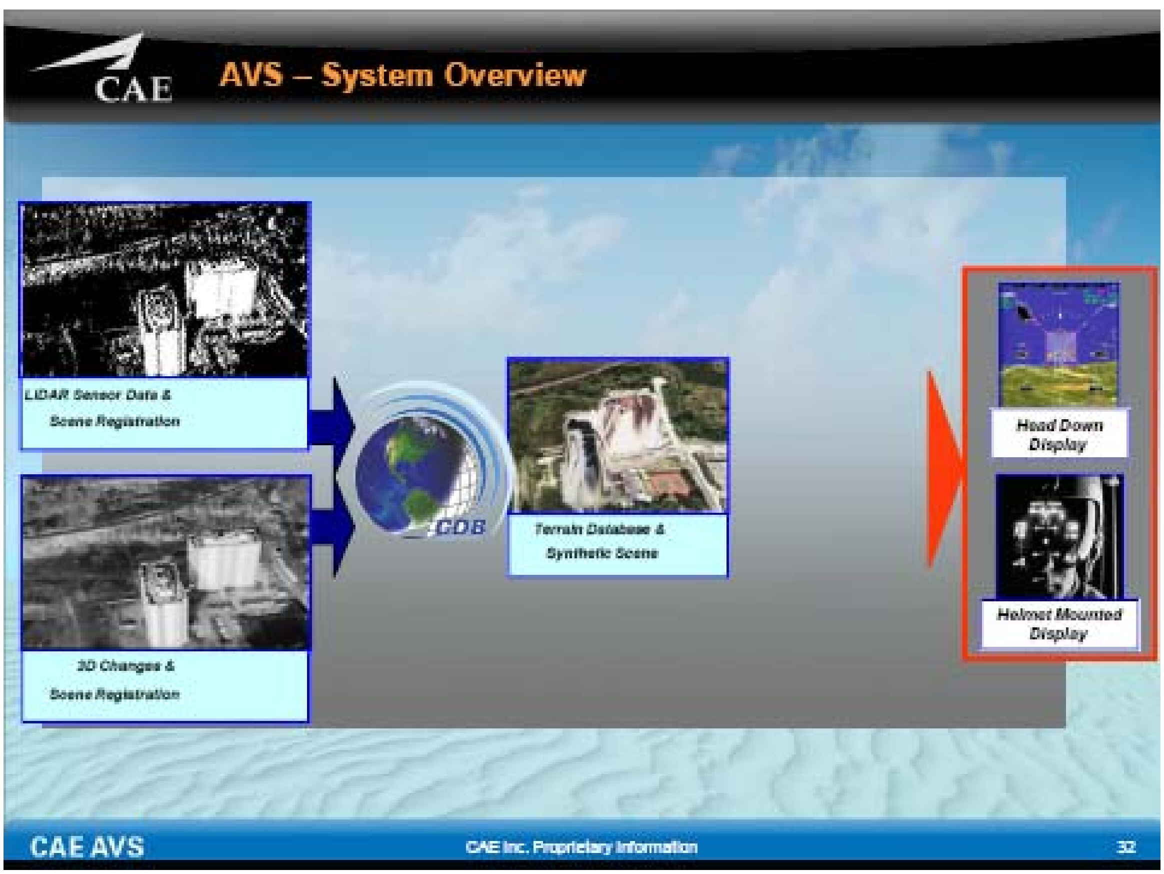

AVS – System Overview
LIDAR Sensor Data &
Scene Registration
3D Changes &
Scene Registration
CDB
Terrain Database &
Synthetic Scene
Head Down
Display
Helmet Mounted
Display
CAE AVS
CAE Inc. Proprietary Information
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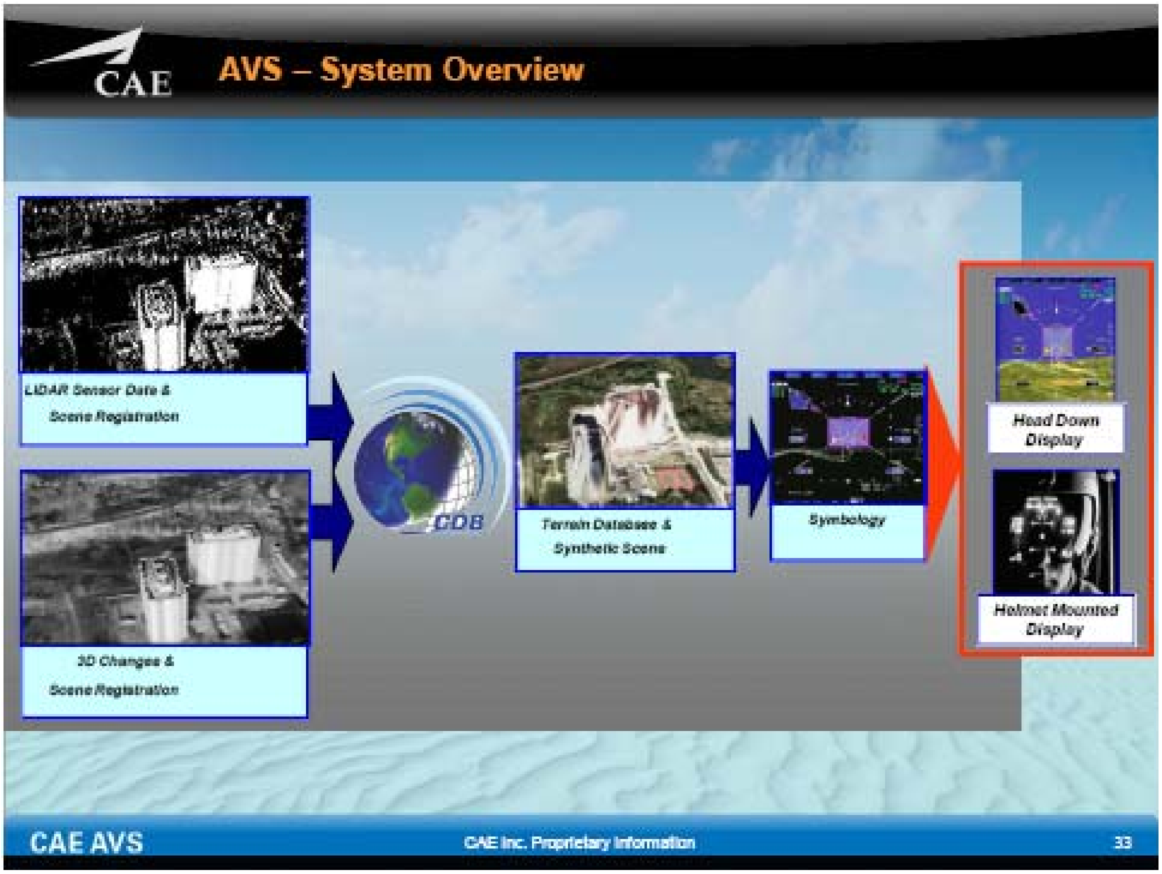
CAE
AVS – System Overview
LIDAR Sensor Data & Scene Registration
3D Changes & Scene Registration
CDB
Terrain Database & Synthetic Scene
Symbology
Head Down Display
Helmet Mounted Display
CAE AVS
CAE Inc. Proprietary Information
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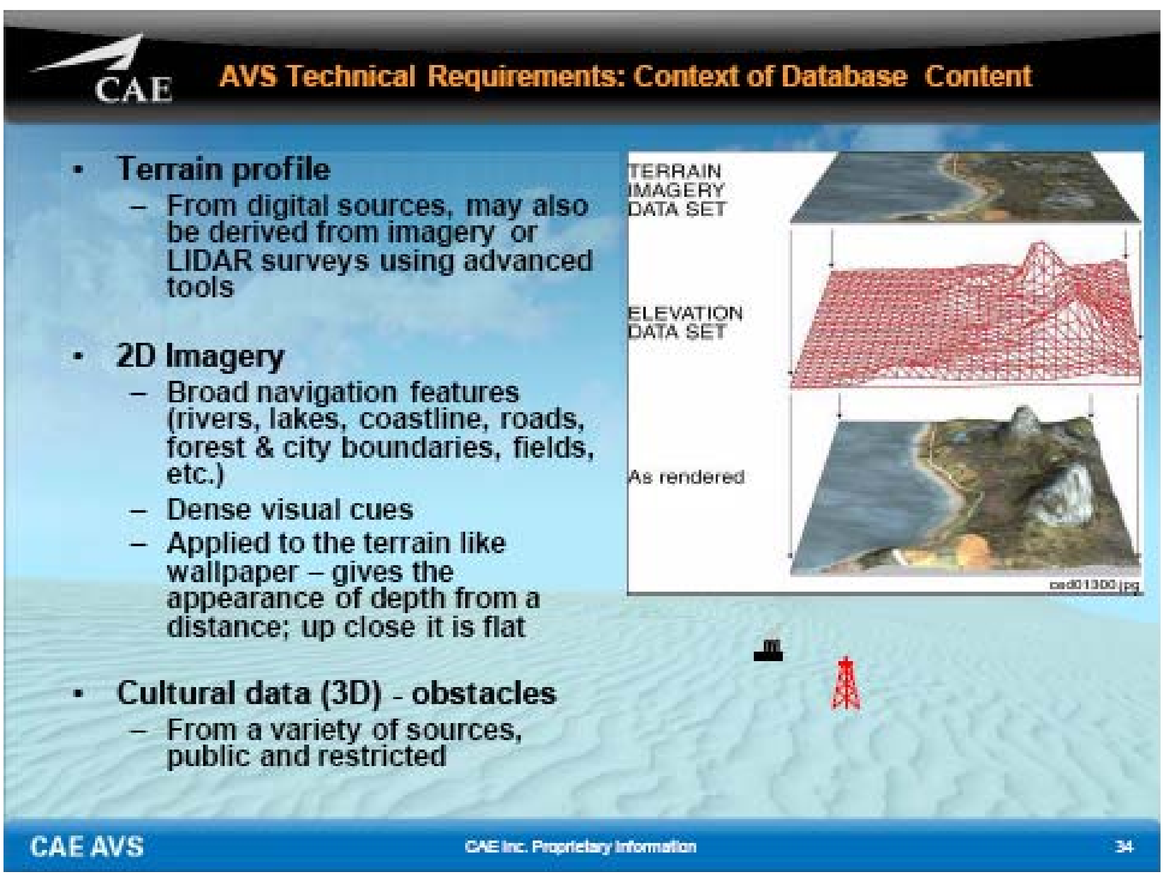
CAE
AVS Technical Requirements: Context of Database Content
• Terrain profile
– From digital sources, may also be derived from imagery or LIDAR surveys using advanced tools
• 2D Imagery
– Broad navigation features (rivers, lakes, coastline, roads, forest & city boundaries, fields, etc.)
– Dense visual cues
– Applied to the terrain like wallpaper – gives the appearance of depth from a distance; up close it is flat
• Cultural data (3D) - obstacles
– From a variety of sources, public and restricted
TERRAIN IMAGERY DATA SET
ELEVATION DATA SET
As rendered
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Database Imagery Source Options: Optimiz ing Performance

- **Geo-specific source imagery:**
  - Preferred choice for landing zones, refers to current satellite/ aerial photography of the database region.
    - Available from commercial and intelligence sources, it can be readily incorporated into the database 24 hrs prior to flight.
- **Pseudo Geo-specific source imagery:**
  - Generated on-the-fly from digital map data, altimetry and high-resolution generic textures where no specific imagery is in the database.
  - Accuracy is as good as the underlying map data.

See examples

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Geospecific vs Pseudo-Geospecific Textures

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CAE **AVS Terrain Database System Evolved from CDB**

- CDB is a runtime synthetic environment database
  - Created under 160th SOAR contract for the MH-47 and MH-60
- Covers the entire Earth at multiple resolutions
  - Tiles the Earth in a quad-tree structure of environmental datasets (elevation, imagery, vector, 3D objects…)
- Single DB feeds all simulation devices (FLIR, IG, CGF, Radar…)
- Supports tactical training and mission rehearsal
  - Supports 24 hour target creation timeline for mission rehearsal

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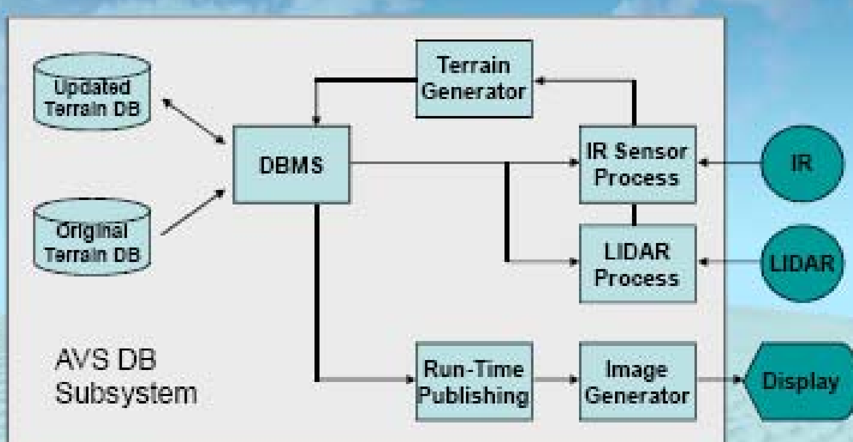
CAE **AVS Terrain Database System Evolved from CDB**

- In the AVS, CDB mission rehearsal synthetic environment run-time publishing evolves into a sensor-driven dynamic terrain database system.



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AVS Flight Test Results (2006-2007)

February 2007 – Develop and Evaluate Ability To Process In-Flight Sensor Data in Real Time

Flight Test LIDAR and IR-Based AVS components and processing to evaluate:

1. Real-time database update through extraction of features from IR imagery
2. Real-time database update through embedding of LIDAR scan data
3. LIDAR Obstacle Detection Through Whiteout

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AVS Flight Test (2006-2007) – testing environment

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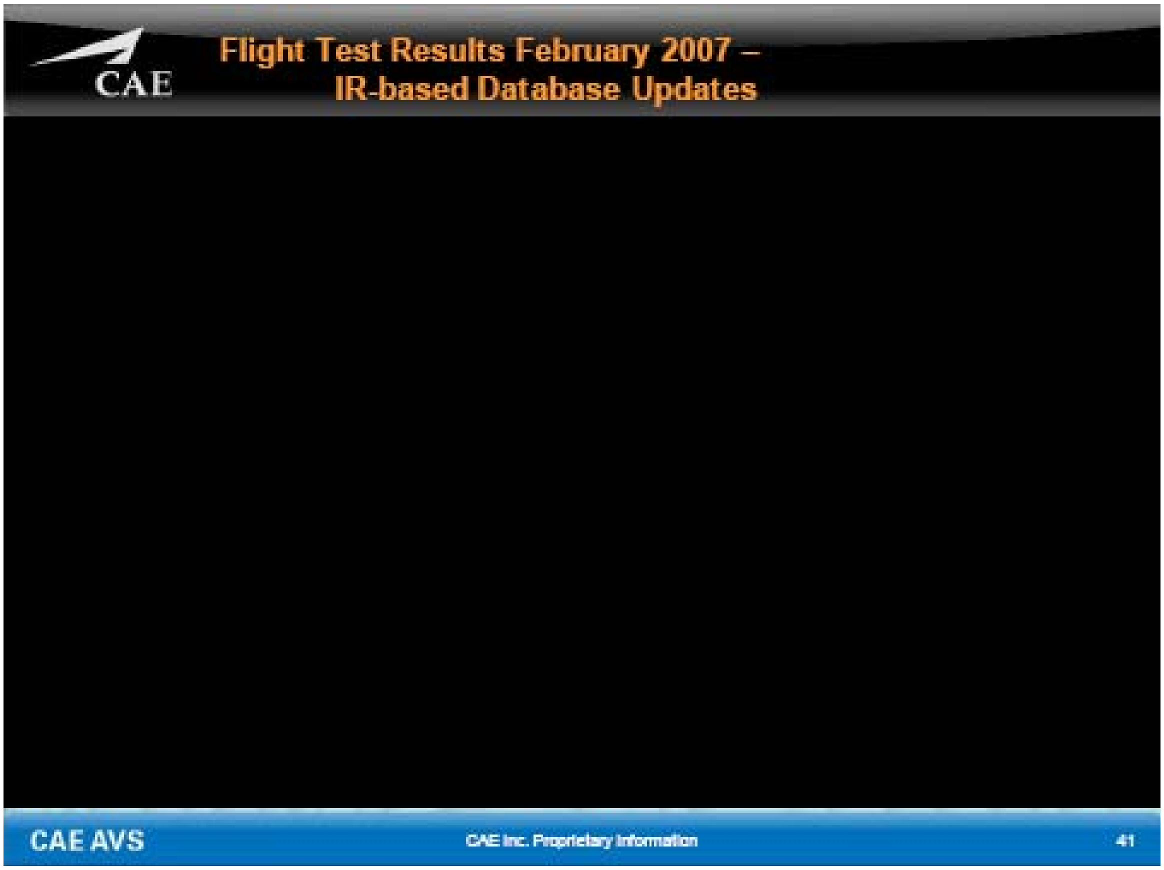
CAE
Flight Test Results February 2007 –
IR-based Database Updates
CAE AVS
CAE Inc. Proprietary Information
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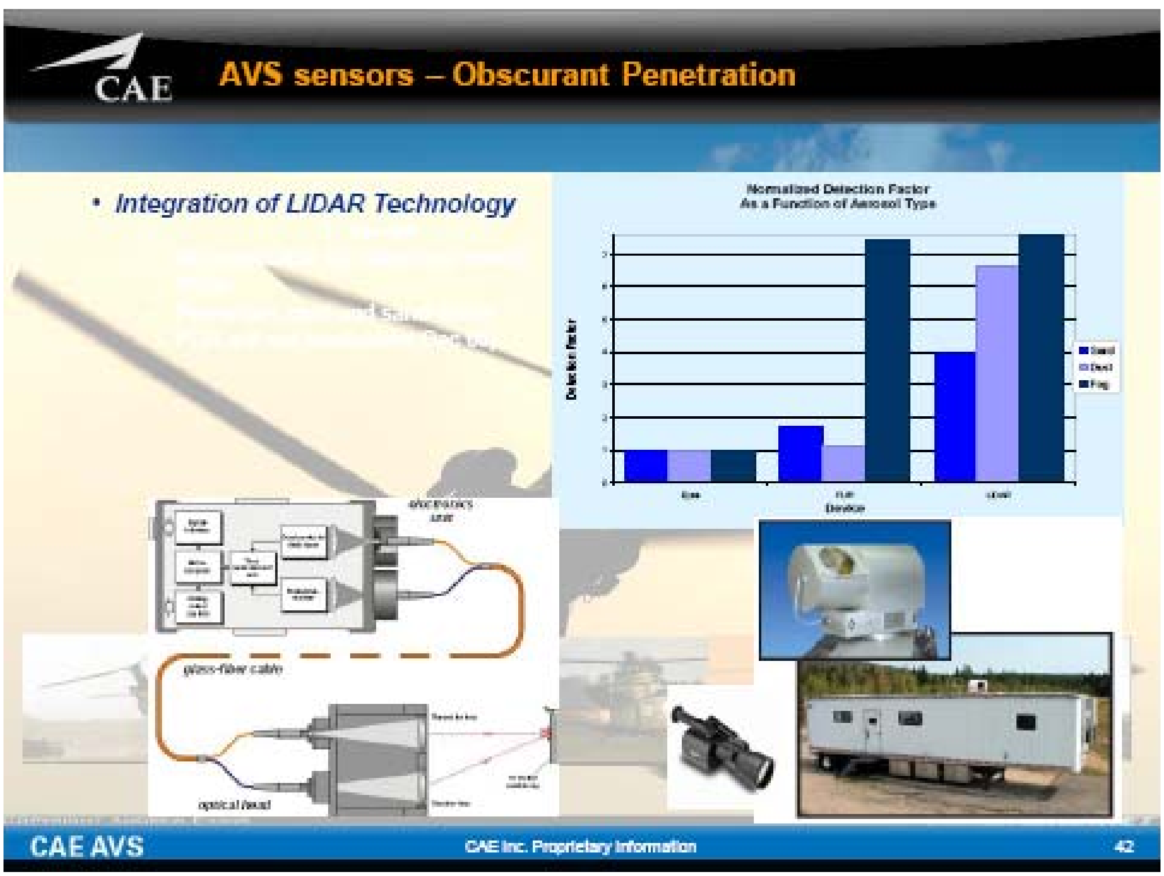
CAE
AVS sensors – Obscurant Penetration
• Integration of LIDAR Technology
Normalized Detection Factor
As a Function of Aerosol Type
Detection Factor
Device
Sand
Dust
Fog
electronics unit
glass-fiber cable
optical head
CAE AVS
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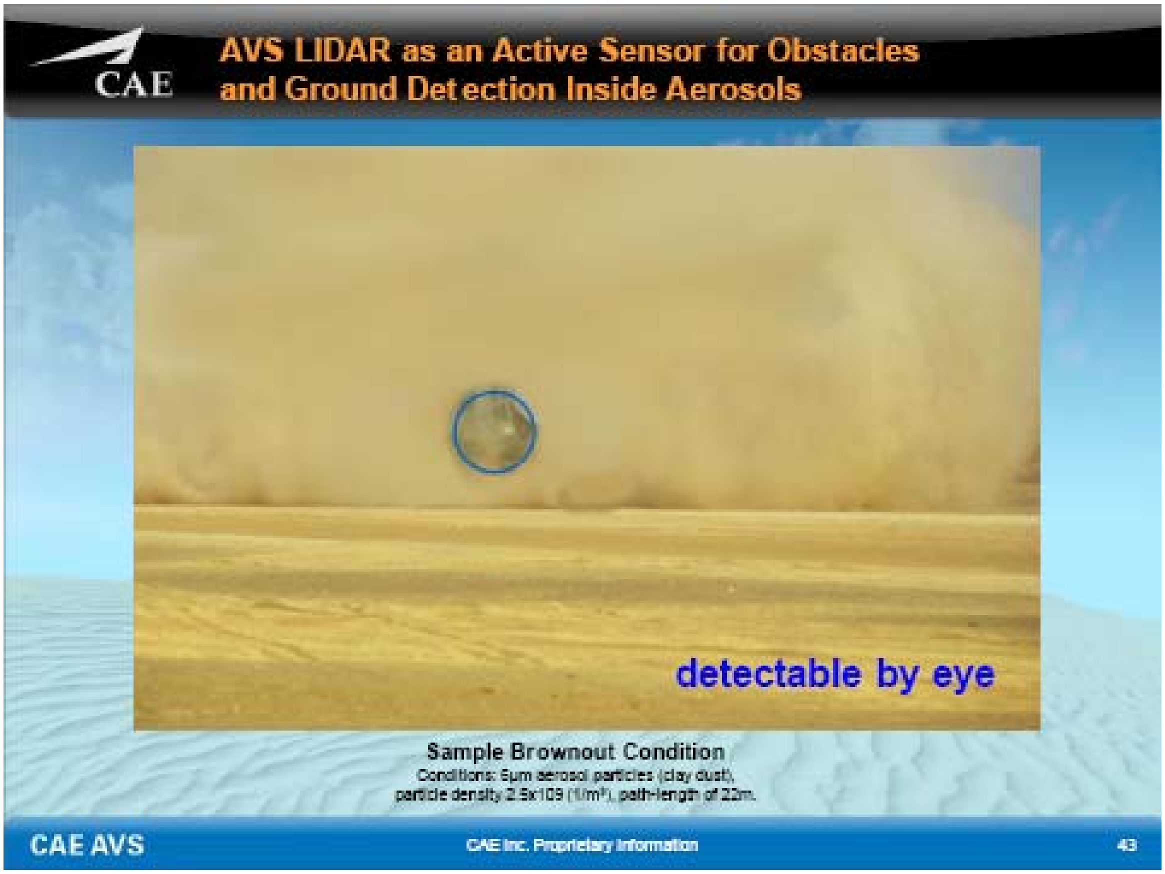
CAE
AVS LIDAR as an Active Sensor for Obstacles and Ground Detection Inside Aerosols
detectable by eye
Sample Brownout Condition
Conditions: 5μm aerosol particles (clay dust),
particle density 2.5x109 (1/m³), path-length of 22m.
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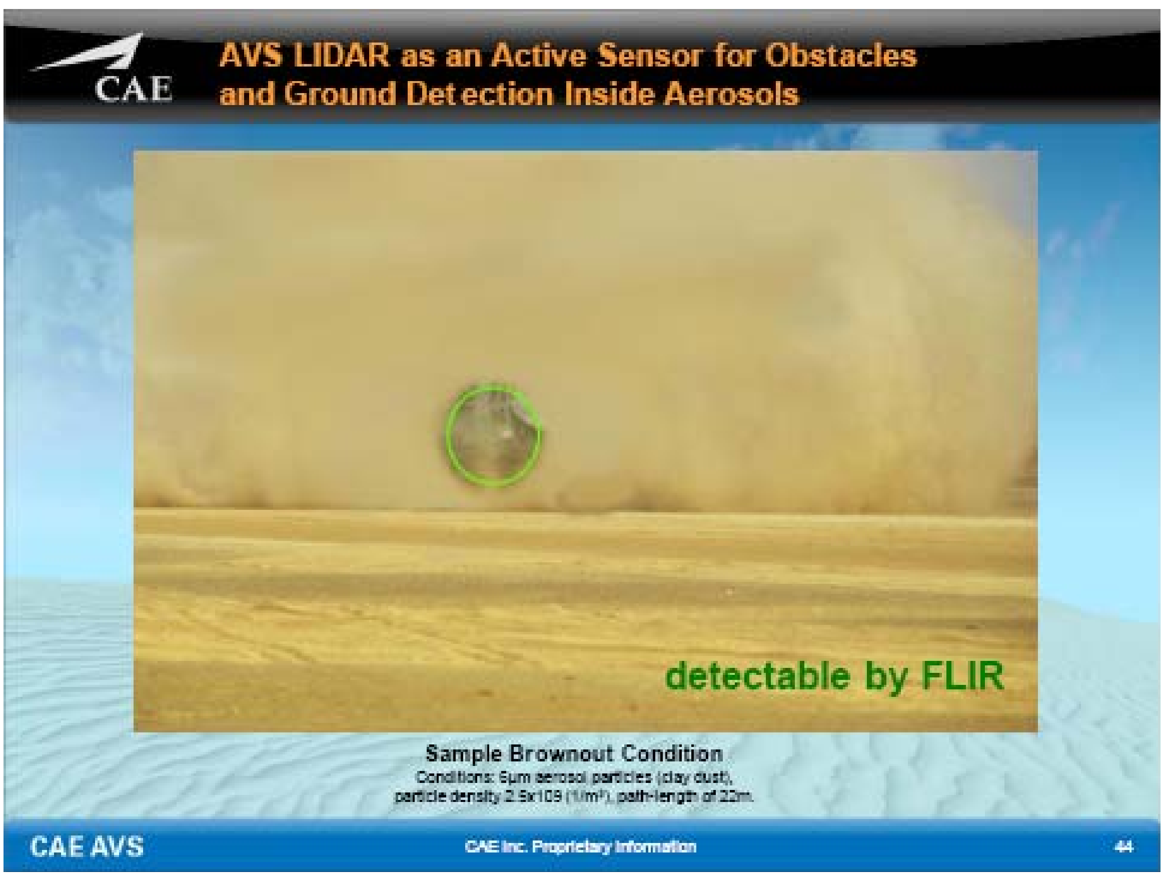
CAE
AVS LIDAR as an Active Sensor for Obstacles and Ground Detection Inside Aerosols
detectable by FLIR
Sample Brownout Condition
Conditions: 5μm aerosol particles (clay dust),
particle density 2.5x109 (1/m³), path-length of 22m.
CAE AVS
CAE Inc. Proprietary Information
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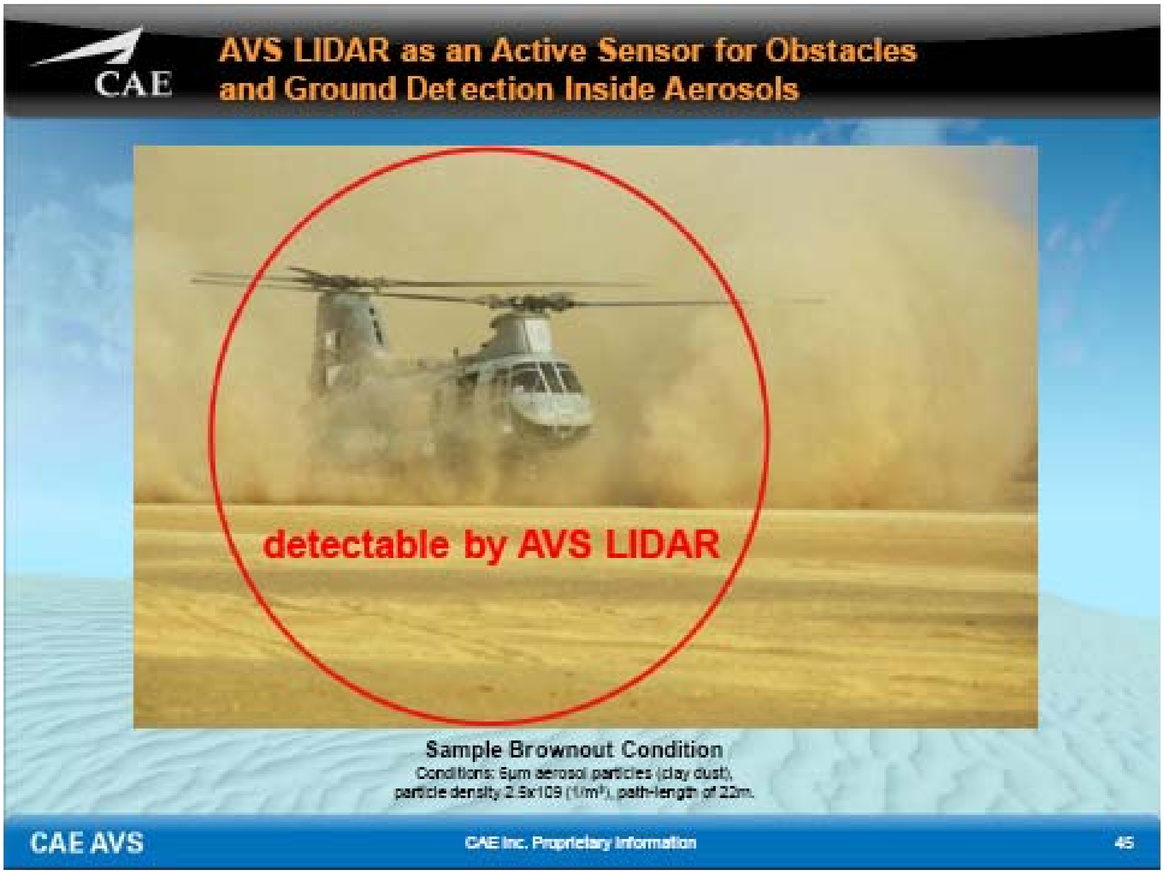
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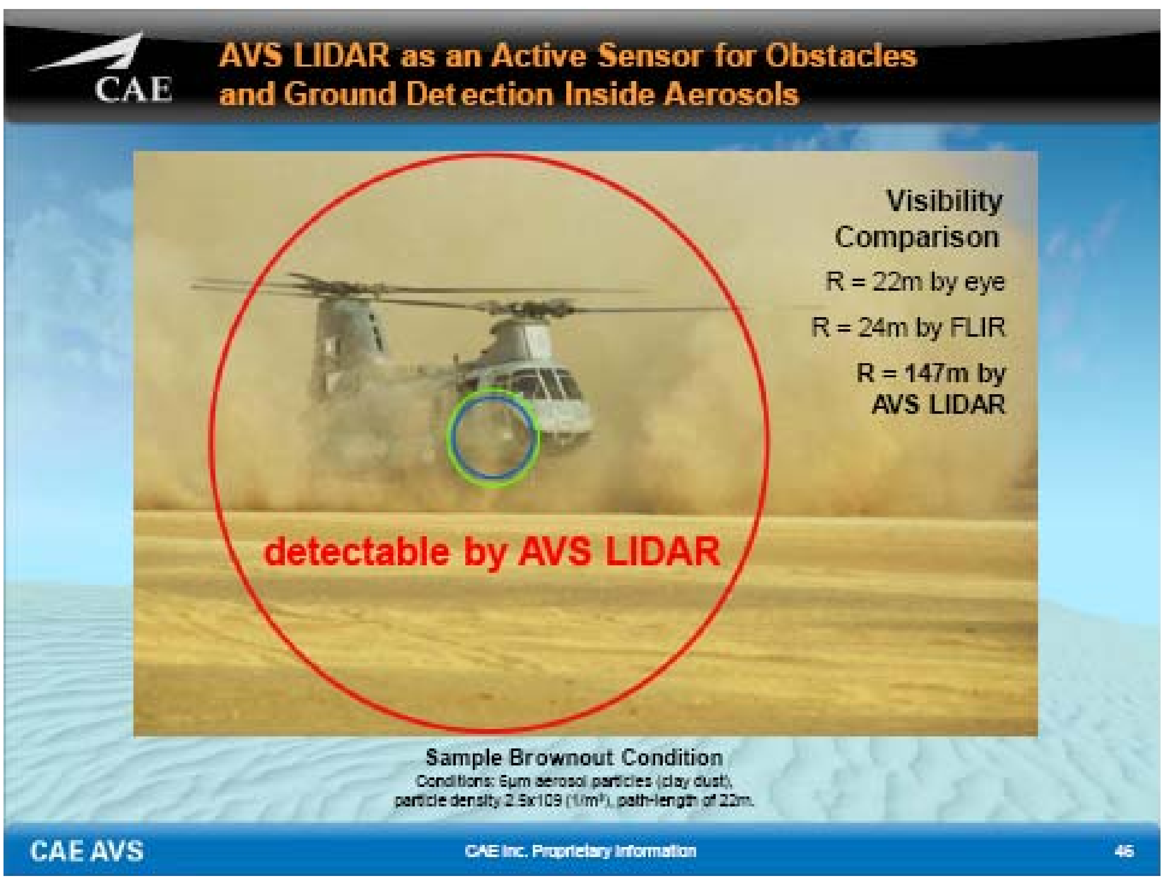
AVS LIDAR as an Active Sensor for Obstacles
and Ground Detection Inside Aerosols
detectable by AVS LIDAR
Sample Brownout Condition
Conditions: 6µm aerosol particles (clay dust),
particle density 2.5x109 (1/m³), path-length of 22m.
CAE AVS
CAE Inc. Proprietary Information
45


CAE
AVS LIDAR as an Active Sensor for Obstacles
and Ground Detection Inside Aerosols
Visibility
Comparison
R = 22m by eye
R = 24m by FLIR
R = 147m by
AVS LIDAR
detectable by AVS LIDAR
Sample Brownout Condition
Conditions: 6µm aerosol particles (clay dust),
particle density 2.5x109 (1/m³), path-length of 22m.
CAE AVS
CAE Inc. Proprietary Information
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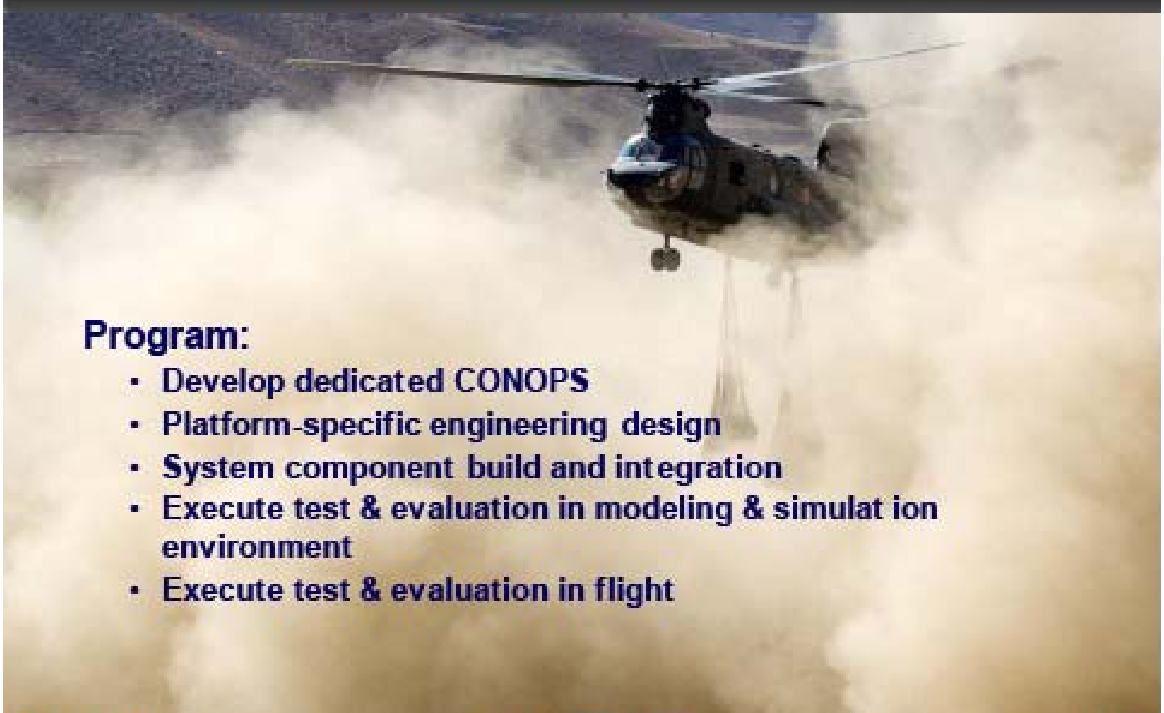
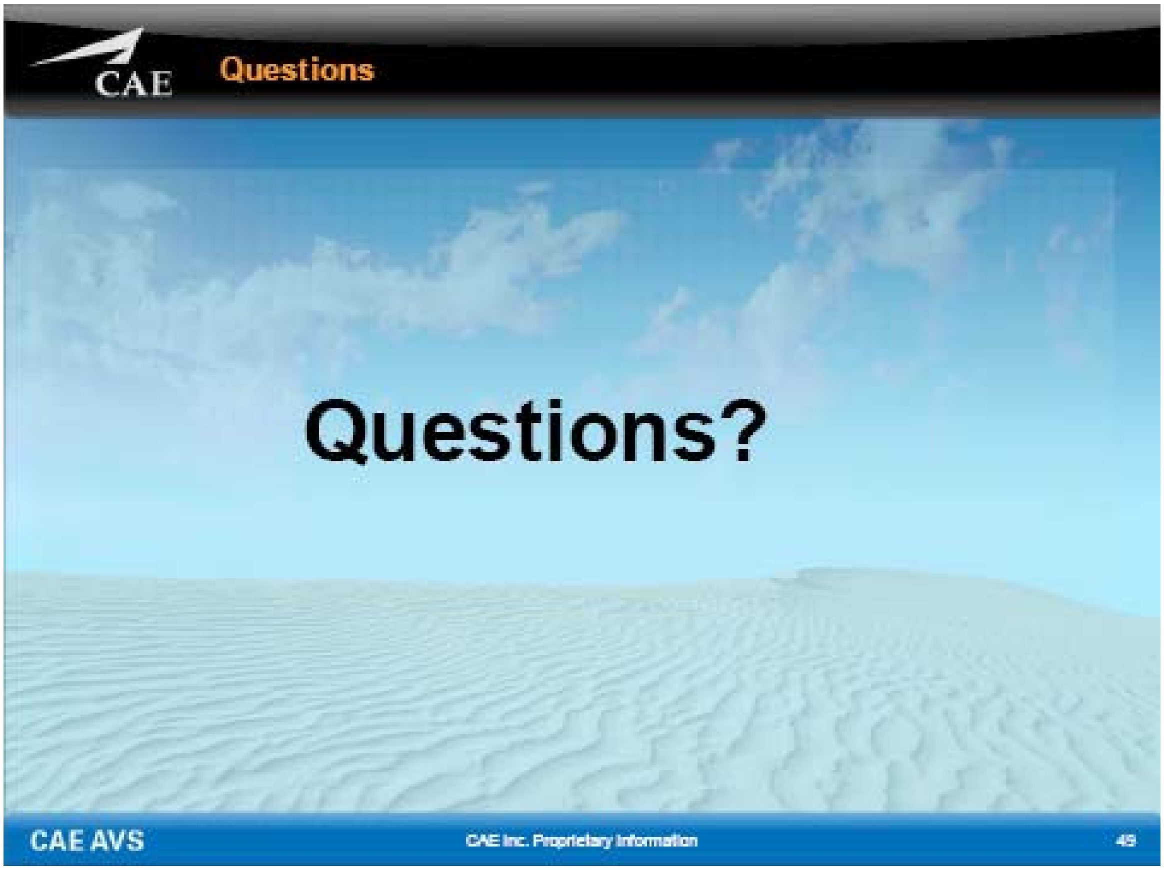
Flight Test Results February 2007 – LIDAR-based Database Updates

AVS: Program Development



Program:

- Develop dedicated CONOPS
- Platform-specific engineering design
- System component build and integration
- Execute test & evaluation in modeling & simulat ion environment
- Execute test & evaluation in flight


CAE
Questions
Questions?
CAE AVS
CAE Inc. Proprietary Information
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Speaker Profile

Dr. Kruk is Chief Scientist at CAE Inc. Prior to obtaining his graduate degrees (PhD in Applied Psychology – Vision, Dalhousie 1983) Dr. Kruk was a pilot in the Canadian Forces. In the last 25 years at CAE he has been involved in development of: control and display systems for aircraft, ships and Air Traffic Control, a series of Helmet-Mounted-Display Systems, Computer Image Generation Systems, Networked Simulation and Synthetic Environments, Fly-By-Wire control systems and controllers for both flight and tele-robotic applications, Enhanced/Synthetic Vision Systems (ESVS) for Helicopter Operations, Augmented Visionic Systems and hybrid/autonomous robotic sensor systems including UAV and UGV applications. He has published 85+ Technical Reports and Journal and Proceedings Articles.

His basic research areas are: Human Sensation and Perception, Cognitive Performance and Modelling, and Learning. His current research interests include: human visual performance; aviation human factors, particularly with respect to ESVS; visual-vestibular-tactile interaction; advanced visual displays and image generation systems; information processing in C4I systems and autonomous sensor networks.

Current professional activities include: Member of the Advisory Committee for the Ontario Centers of Excellence; Member of the Advisory Board of the National Research Council of Canada Institute for Aerospace Research; Executive member of the SAE G-10 Aviation Human Factors Standards Committee (Chair Synthetic Vision Subcommittee, Co-chair UAS Subcommittee).

Multi-Spectral Enhanced Vision System

Dinesh Ramegowda, HTSL, Bangalore

Controlled-flight-into-terrain (CFIT) and approach and landing accidents (ALA) are the major causes of commercial accidents according to the Flight Safety Foundation. Honeywell has recently introduced the launch of a new synthetic vision safety product line called Integrated Primary Flight Display (IPFD) that uses the Enhanced Ground Proximity Warning System (EGPWS) global terrain database to present a three-dimensional view of what the pilots would see out of the windshield on a clear day. Because IPFD is based on archived information (taken at earlier time than the time of the flight), the data can be impeded by erroneous or missing data. In addition, there is no means to identify and detect moving obstacles that are not registered in the database. The Enhanced Vision System (EVS) compliments Synthetic Vision System (SVS) with on-board imaging sensors, which offers liveliness to the database. Since no single sensor cover all possible weather situations, the drive is to employ multi spectral sensors to complement each other so that discrepancies are rectified. The choice of sensor, the requirement and signal processing of sensor suites are strongly dependent on given operation and its criticality. In this talk, we discusses following key aspects of multi-spectral EVS

- Choices for EVS sensor suites among Long wave IR (LWIR) camera, Short wave IR (SWIR) camera, Electro optical (EO) camera, active/passive and 2D/3D Millimeter wave radar (MMW)
- Sensor selection based on their characteristics (wavelength, FOV, range resolution, visibility range etc), cost, compactness and associated processing
- Pre-processing of individual sensor signals to improve noise suppression and dynamic range compression
- Image registration and fusion of multiple image streams
- Spatio-temporal video analytics to extract runway structures and other additional features to enable pilots to easily navigate to the airport,
- identify potential hazards to take avoidance action, and obtain sufficient visual reference of the runway for a safe landing
- Integration with other navigation aid such as GPS Landing Systems (GLS), Automatic Dependent Surveillance – Broadcast (ADS-B), Traffic Collision Avoidance System (TCAS) etc.

MULTI-SPECTRAL ENHANCED VISION SYSTEM

Dr. Dinesh R
Honeywell Technology Solutions
Bangalore

Honeywell

Presentation Overview

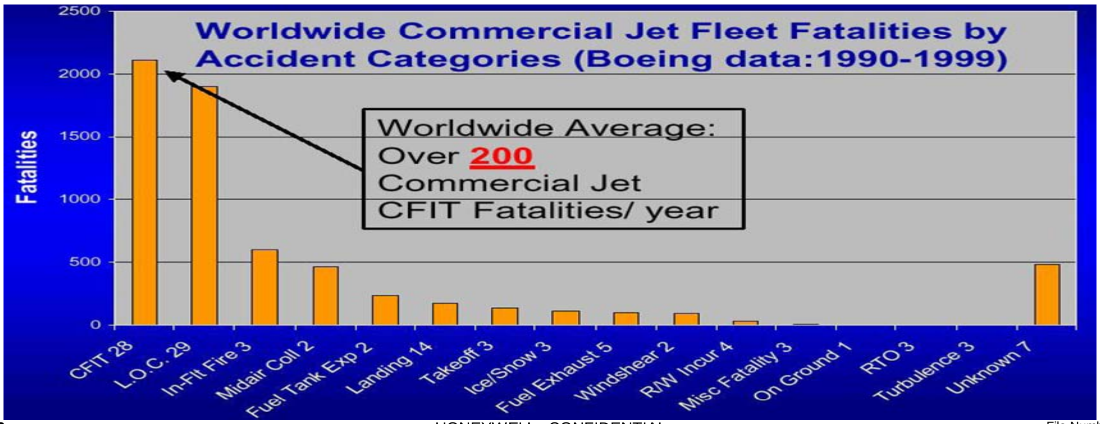
Honeywell

- Need for SVS
- Definition and application of SVS
- Challenges in building SVS
- Limitations of SVS
- Need for EVS
- Need for Multi spectral EVS
- Challenges in Building EVS
- EVS @ Honeywell
- Summary

CFIT AND RUNWAY INCURSIONS – A WORRY

Honeywell

- Controlled-flight-into-terrain (CFIT) and approach and landing accidents (ALA) are the major Causes of commercial accidents according to the Flight Safety Foundation.
- The Advisory Council for Aeronautics Research in Europe (ACARE) in its recent report on Challenges in Air transport safety has collected statistics on various factors for aircraft accidents and aptly set its vision for year 2020 as *"80% reduction of accident rate, with particular focus on drastic diminution of human error"*



AIRCRAFT ACCIDENTS – CAUSE AND EFFECT

Honeywell

Cause

One common denominator is that their occurrence during times of reduced visibility, when the pilot is unable to see the danger ahead until it is too late.

Triggers everyone

- Even Federal Aviation Administration (FAA) emphasized the necessity for pilots to have good situational awareness (knowing where the aircraft is and where it is heading to) to minimize such accidents.
- The Human Factors Team (SA-1) of the FAA quotes:

> *"The FAA should require operators to increase flight crews understanding of and sensitivity to maintaining situation awareness, particularly, position awareness with respect to the intended flight path and proximity to terrain, obstacles or traffic.*

AIRCRAFT ACCIDENTS – CAUSE AND EFFECT contd…

<u>Attempt</u>

Some of the ongoing research efforts to tackle such problems are development of

1. Automatic approach system (Auto Pilot)
2. Precision approach/landing system (ILS)
3. Tactical decision tools
4. Vision systems – Synthetic Vision System (SVS), Enhanced Vision System (EVS), Hybrid Vision System (HVS) etc

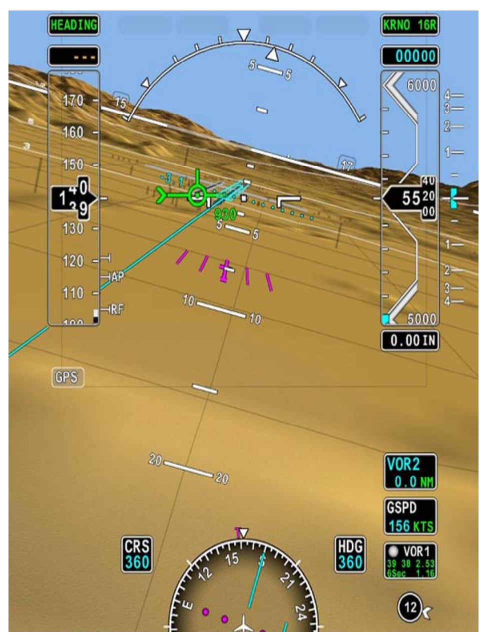
All for one common goal : better situation awareness for Crewmembers

<u>Vision system development – a special attention</u>

- National Research Council in its report on Decadal Survey of Civil Aeronautics, has aptly listed SVS and EVS as one of the top fifty one research and technology challenges for NASA in the next decade.
- The National Institute of Aerospace in its report delivered to US Congress on federal investment plan for civil aeronautics research has recommended $ 7.8 M spending for SVS/EVS research

SYNTHETIC VISION SYSTEM (SVS) DEFINED!

The synthetic vision is a computer generated image of the external scene topography that combines pre-recorded terrain maps with flight instrumentation information (attitude, altitude, airspeed, pitch/roll ladder etc from say. ARINC 429 bus), Highway In the Sky (HITS) tunnel holding information on flight path and profile and present the pilot with a perspective view of the ground ahead.



SVS – POTENTIAL UNBOUND

Honeywell




Synthetic Vision Systems (SVS) are regarded as a candidate technology to increase safety and/or enable operations that are impaired by reduced visibility conditions.

Synthetic Vision System (SVS) technology can contribute to an increase in safety by compensating for the loss of information caused by reduced visibility conditions.

SVS – POTENTIAL UNBOUND

Honeywell

- **Manually fly complex trajectories in an obstacle-rich and/or terrain-challenged environment**
- **Continue to lower visual minima**
- **Separation between planned path and terrain**
- **Deviation of the aircraft from the path**
- **Current and expected separation between aircraft and terrain**

SVS CHALLENGES

Honeywell

The extent to which operational minima can be reduced to increase operational capabilities will depend on overall system integrity.

- Important issues need to be addressed are
  - The quality of terrain
  - Flight path, airport, obstacle and position data
  - The ability to detect errors/omissions in a timely manner.
- It is unlikely that a terrain and obstacle database will be completely error-free.
- SVS-enabled operations that rely on a database of the environment in order to go below the minima of current operations will need to assure an equivalent level of safety.

HONEYWELL – A PIONEER IN SVS

Honeywell

Honeywell has demonstrated a SVS (in the name of Integrated Primary Flight Display, IPFD) that uses refined terrain and obstacle data from its own Enhanced Ground Proximity Warning System (EGPWS) to give a computer generated picture of the environment ahead on aircraft flight displays

Why Pilots Love IPFD

Honeywell

AMBIENT quality reduces data gathering effort.

The data is all around the pilot, and the pilot is in the data.

Sensed temperature is all around; no point thermometer checks are required.

NATURAL quality reduces data interpretation effort.

The data is presented without a requirement for mental rotation and recombination.

Sensed temperature is just as it feels; no Fahrenheit-Celsius conversion is required.

CONTINUOUS quality reduces data update effort.

The data is continually updated in the primary field of view without time- or priority-sharing burden.

Sensed temperature updates in real time; no periodic thermometer checks are required.

IPFD in Perspective

Honeywell

- **Sperry Horizon to IPFD**
  - **Ambient, natural, and continuous qualities**
  - **Reduce pilot burdens to gather, interpret, and update data.**
- **Differentiators**
  - **Human Centered Design basis and validation**
  - **EGPWS database reliability and robustness**
  - **Epic Graphics Platform/INAV capability and integration**
- **Benefits**
  - **Higher Situational Awareness**
  - **Lower Workload**
  - **Easier Training**
  - **Improved Safety**

Views that pilots naturally understand,
cues that pilots already know,
systems that pilots trust

Limitations of SVS

Honeywell

- An artificial depiction of the environment
  - Insists on optimize the presentation, i.e. emphasize relevant information, eliminate non-relevant information
  - What's not in the database is not shown!
  - Update rate is determined by computer performance

- Inaccuracies and/or errors in the obstacles database
  - Inaccuracies and/or errors in the airport database

MOTIVATION FOR ENHANCED VISION SYSTEM

Honeywell

- The need to land and taxi aircraft in degraded weather conditions.

  Approaching zero-zero is driving sensor fusion and the need for advanced video analytics technology

- Pilots need to have a good situational awareness of the outside world.

  Heavy fog, smoke, snow, dust, or sand, to detect both moving obstacles (e.g., another aircraft) and stationary obstacles (e.g., tower that was not in database) along the approach path, runway or during taxi

- There is no means to identify and detect moving obstacles that are not registered in the database.

ENHANCED VISION SYSTEM (EVS) DEFINED

Honeywell

- EVS combines *"properly"*, the complimentary and/or supplementary information from different sources, for example, extracted runway structures, to estimate the relative position of aircraft with respect to runway.
- Sensor (data) information is combined with SV, ATC and navigation data to provide an out-the-window view of terrain, obstacles and traffic on Head-Up Display (HUD).
- To provide all weather operation capability to SVS, Enhanced Vision System employs one or more of onboard weather penetrating imaging sensors like Forward Looking Infrared (FLIR), imaging radars, laser ranging sensors etc.

OPERATIONAL BENEFITS OF EVS

Honeywell

The operational and safety benefits of EVS are foreseen from the following perspectives

1. Crew assistance in connection with
   - Adverse weather
   - Obstacle detection
   - Landing operations down to CAT III minimums. With EVS, pilot can continue the approach from Decision Height (DH) or Minimum Decision Altitude (MDA) down to 100 ft AGL (Above Ground Level) leading to increased accessibility of airports (even of non-equipped airports) under low visibility operations.
2. Integrity monitor for
   - On board navigation data (Differential GPS, INS)
   - SV airport database, terrain database

OPERATIONAL BENEFITS OF EVS contd…

Honeywell

3. Automatic flight guidance in terms of
    - Image based navigation – curved approach:

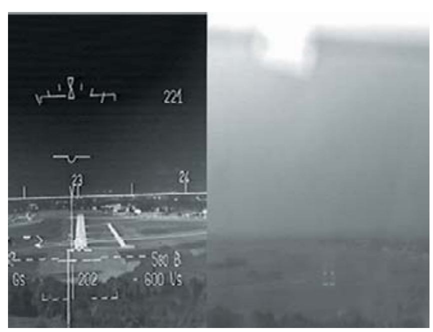
      it becomes practical to realize curved approach in airports with surrounding terrain that makes a long straight in ILS approach impossible
    - Image based navigation – closely spaced parallel landing:

      currently, minimum space between runways to allow parallel approaches in poor visibility is 3400 feet. With EVS, this can be reduced to 750 feet as pilots can see other aircraft in HUD display through EVS rendered image
    - Collision with ground vehicles be avoided
    - Avoidance of terrain and CFIT
    - Reducing runway occupancy error, taxiing error and gate-to-gate travel time as EVS renders image of the airport area with runways, taxiways, gates and buildings.
    - Reducing number of go-around (missed approaches)

OPERATIONAL BENEFITS OF EVS – SUMMARY

Honeywell

		Advantage	Disadvantage
	Synthetic Vision	easy image interpretation	no obstacle detection reference system necessary depends on data base reliability
+	**Sensor Vision**	obstacle detection no reference system necessary no data base necessary	difficult image interpretation
+	**Aircraft status**	already available	single sensor information
+	**ATC data**	identification of other aircraft	needs data link technology
=	**Integrated Enhanced Vision System**		



REQUIREMENTS FROM EVS SENSOR

Honeywell

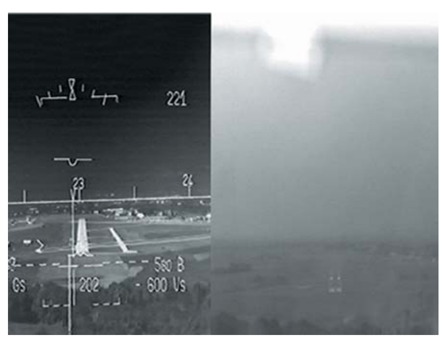
The requirements for suitable imaging EVS sensors depend strongly on the application.

	operational requirements	resulting requirements for imaging sensors
civil	• reduction of minimum approach RVR • reduction of minimum takeoff RVR • safe taxi operations • obstacle warning in critical phases • CFIT warning • integrity monitor for GPS supported navigation • search and rescue	⇒ weather independent ⇒ sufficient resolution ⇒ image rate > 15 Hz ⇒ image delay < 200 ms ⇒ coverage minimum = HUD coverage
military	• low level flights • landing on unsupported forward operating strips • precise air dropping • air surveillance • ground mapping for surveillance	⇒ passive or "silent" sensor ⇒ autonomous; ground facilities not necessary ⇒ reconnaissance capability

IR CAMERA – A NATURAL CHOICE

Honeywell

- **Low cost**
- **Generates a perspective 2D kind of image, which the human visual perception system is evolutionary trained to process into a 3-D representation of the "outside world".**



IR CAMERA BASED EVS – LIMITATIONS

Honeywell

- IR images generally suffer from the poor quality due to temperature sensitivities
- Low signal-to-noise ratio and a narrow dynamic range
- FLIR sensor is not an all-weather solution.
- FLIR images, which show only thermal differences, can be confusing during certain conditions

→ **MULTI SPECTRAL EVS – EMERGING TREND**

MULTI SPECTRAL EVS - DEFINED

Honeywell

- Integration/fusion of SVS with EVS
- Multisensor Image Fusion is the process of combining relevant information from two or more images from different source into a single image.
- The image fusion techniques allow the integration of different information sources. The fused image can have complementary spatial and spectral resolution characteristics.

Why?

- Terrain elevation databases cannot be guaranteed to be error free
- The integrity of the elevation data is unbounded
- To provide the possibility to timely detect dangerous discrepancies

MULTI SPECTRAL EVS – SENSOR FUSION IS KEY

Honeywell

The visual information provided by fusion of image data from onboard multi spectral sensors with synthetic vision system, supported by an ATC interface and aircraft state data (position, attitude, speed, etc.), will be a key tool for aircraft guidance.

MULTI SPECTRAL EVS – SENSOR CHOICE

Honeywell

Sensor Type	Wave-length [micron]	Kind of image	Active/ Passive	Ground Facility	Angular resolution [degree]	Range Resolution [m]	Rate [Hz]	Delay [sec]	FOV HxV [degree]	Visibility Range [Km]
UV	0.2-0.3	2-D Optical	Passive	Yes	0.05	NA	NA	NA	30x22	0.8
Video	0.4-0.8	2-D Optical	Passive	No	0.05	NA	25		Variable	NA
LADAR	1.54	2.5-D range-angle-angle	Active	No	0.35*0.20	1	2-4		32x32 Range 1Km	NA
IR	3-5	2-D Optical	Passive	No	0.05	NA	25		Variable	NA
IR	8-12	2-D Optical	Passive	No	0.05	NA	25		Variable	NA
MMW 94GHz	3190	2-D range angle	Active	No		3	10		30 x 22	NA
MMW 77GHz	3900	Variable	Active	No	0.25	1.2	NA	NA	250 meters	NA
PBMMW 35GHz	8570	2.5-D range-angle-angle	Active	No	2.5	5-10	0.5-1.0	1-2	50 x 20 range 1-3Km	3.0

Challenges in Sensor Fusion

Honeywell

- Two aspects of information fusion need to be addressed are fusion of multiple image types from on-board image sensors and synthetic Vision (SV).
- Common task of image fusion in literature is registration of images of the same type of data.
- A typical challenge in a sensor fusion framework is to have to register two images with different point of view or luminance or level of noise.

Challenges in Sensor Fusion contd…

Honeywell

- Fusing images of different types have several challenges in them.
  - variations in representations
  - Transform the images to one common format.
- Also, in some sensors, the fusion in space is required to overcome the deficiency of certain information (say lack of height information in MMW radars).
- The other challenge in fusing different image types is that it should cope up with ambiguous, incomplete and contradictory nature of information.

Challenges in Sensor Fusion contd…

Honeywell

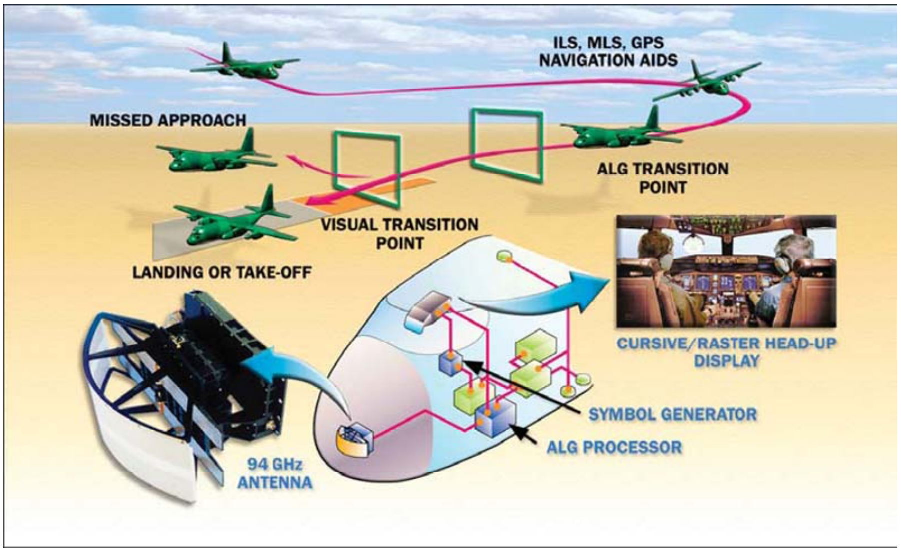
Image registration of sensor and synthetic data is slightly different because the framework involves totally different type of datasets, real data and a model based on different attributes.

- Synthetic model is rendered from database attributes with some information that may not be up to date – which may cause discrepancies between synthetic data and reality (sensor data).

- SVS data does not usually reflect the true view of the world. Thus standard fusion techniques cannot be applied.

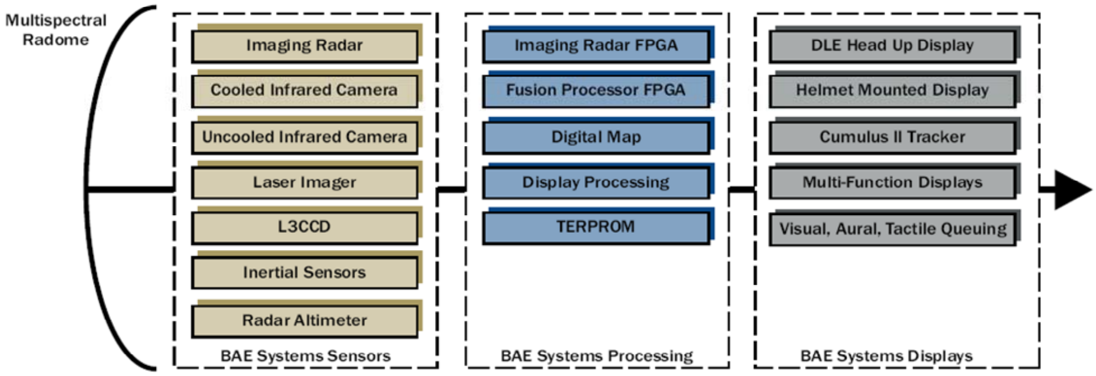
STATE OF THE ART EVS BAE SYSTEMS

Honeywell



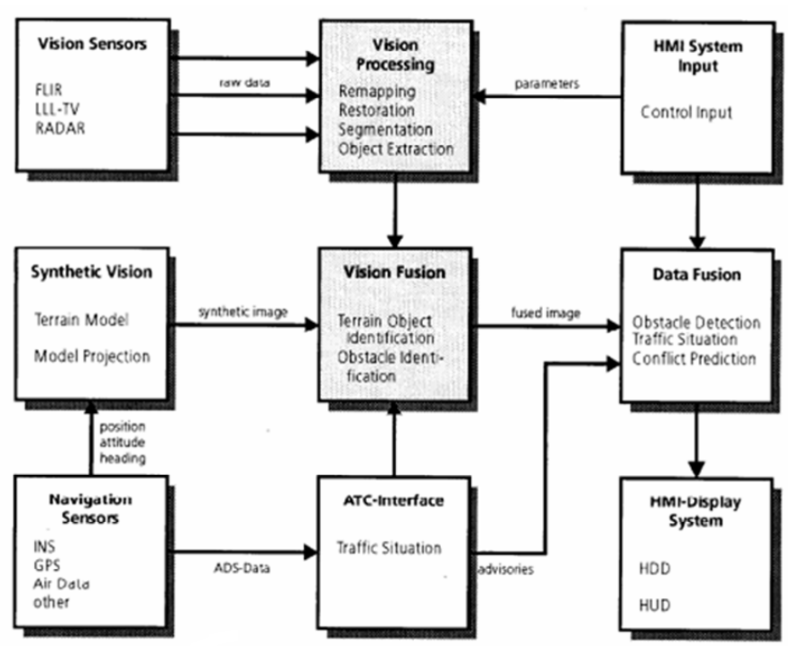
STATE OF THE ART EVS
BAE SYSTEMS

Honeywell



STATE OF THE ART EVS
GERMAN AEROSPACE CENTER (DLR)

Honeywell



Block Diagram of the DLR "Integrated Enhanced Vision System"

EVS @ HONEYWELL

Honeywell

- Development of Computer Vision based system for improving the safety capability of aircrafts during landing mission.
- Exploiting the cues from IR imageries during reduced visibility conditions (night, snow, fog, rain etc), to help in reducing CFIT (Controlled Flight into Terrain) accidents and runway incursion accidents.
- Improved situational awareness to pilots by combining the sensor image and its extracted cues with Synthetic Vision System (SVS).

EVS @ HONEYWELL contd…

Honeywell

- **Contrast enhancement of IR imageries for better perception and processing.**
- **Robust and real – time detection and tracking of runway boundaries with advanced computer vision concepts.**
  - **Hough Transformation based**
  - **Vertex Based**
  - **Template Matching based**
- **Reliable detection of moving objects on and around runway region.**

Scope for future work

Honeywell

- Some of the other research areas requiring attention are
  - Object detection and avoidance
  - HMI interface issues
- Increased machine contextual understanding to reduce pilot's workload
  - Verification of accuracy, fault tolerance and reliability
- The future autonomous vehicles for military (say battlefield) and commercial applications (say mining operations) might require EVS like capability for enhanced perception, improved situational awareness, and collision alerting purposes.
- Proving these concepts as navigation aid for aircrafts to obtain FAA's certification remains a challenge. Once certified, airlines can definitely benefit from operational benefit and hence economical benefits of EVS.

References

Honeywell

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34 HONEYWELL - CONFIDENTIAL File Number

Honeywell

Thank You

Speaker Profile

Dinesh is a Lead research scientist with HTS - Research. His areas of research interest includes Image processing, Pattern Recognition, Computer Vision and Document Image Analysis. He has over 35 publications to his credit at both International and National Journals and conferences. He has been identified as reviewer for several International Journals/conferences. He has served as program committee member for several National / International Conferences. He has successfully guided many academic projects.

He is a life member of Computer Society of India and Society of Statistics, Compute and Applications.

Development of Advanced Image Processing and Image Fusion Algorithms for Extraction of Complementary Information from Various Imaging Sensors

Dr. S C Jain, Sc G, DEAL, Dehradun

Image Processing Software for Archival and Data Management, image Visualization & Interpretation, Image Mosaicking, Geo-referencing, Fusion of Image & Raster maps, Multi sensor data Fusion, Change detection, Generation of annotated Products, SAR Processing, Image Navigator, Multispectral Classification and target detection will be covered.

Archival and Data Management: The purpose of the software is to provide facility to create and manage image database which interacts with various packages. Visual & Tabular queries are provided to retrieve images of interest based on place name, latitude-longitude and other parameters of image.

Visualization & Interpretation: Multiple image formats representing large imageries of different satellites and sensors can be handled. Area of View and Area of Interest concept has been used for handling very large images. Algorithms and Tools for Pixel/Image Manipulations, region/Area of Interest extraction, Image Enhancement filter banks, Image zooming, rotation, panning and roaming, auto scanning of full scene & measurement tools in different units will be covered.

Image Mosaicking: The software for joining of adjacent images with and without overlap to provide continuity in features and represent images as a single entry.

Fusion of Image, Raster maps and Geo-referencing: The software for fusion of different satellite imagery, fusion of image with raster maps, Geo-referenced images can also be generated.

Change detection: The software for detection of changes in multi-temporal Panchromatic and Multi-spectral images along with the steps involved and different methods will be covered.

SAR Image Processing: The software tools for the analysis of SAR images will be dealt in the talk. Fusion software is capable of handling Optical and SAR data and fuses them for enhancing the interpretation capability. SAR Change Detection is capable of detecting temporal changes between two SAR images. Interferometry for height extraction and polarimetric methods for target detection will be covered.

Image Navigator: Image Navigator is designed to visualize the 3D model of large terrain. This software uses the DTED, satellite imagery to create the realistic 3D scene of the terrain. The atmospheric effect like fog, mist, horizon, sky, day/night effects can be introduced. User can navigate the digital terrain using mouse control. Flying over the digital terrain over the pre-stored flight path is possible. The software for control of different viewing directions and other parameters will be taken up.

Multispectral Classification: Multispectral Classification software package is capable of classifying multispectral satellite images in various land cover categories. Classified materials are overlaid on original image in different colors along with legends.

Target Detection: Software for Build Up, desert area extraction capable of extracting and highlighting built-up area, buildings and roads in high resolution images are covered.

Product Generation: Software for generation of annotated products with user defined scale & grid and other parameters will be covered.

DEAL

1

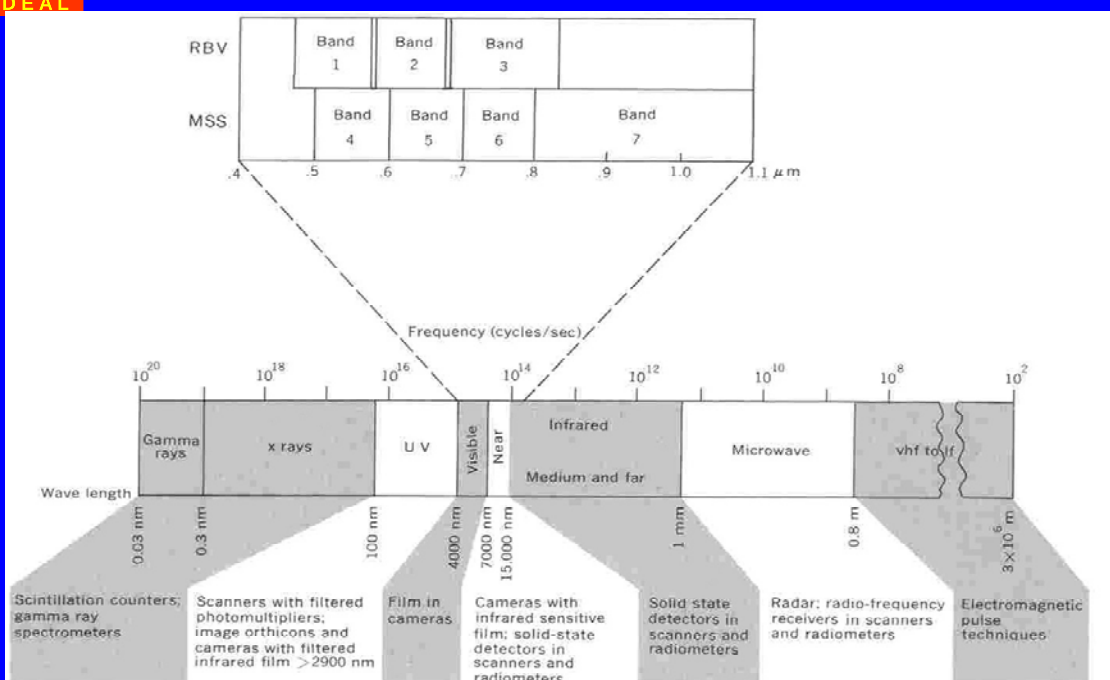
IMAGE PROCESSING TECHNIQUES

S. C. JAIN
DEAL DEHRA DUN

DEAL

2

ELECTROMAGNETIC SPECTRUM



The electromagnetic spectrum and ERTS–1 sensor relationships. (Modified from Parker, D. C., and Wolff, M. F., 1965, Remote sensing: International Science and Technology, July.)

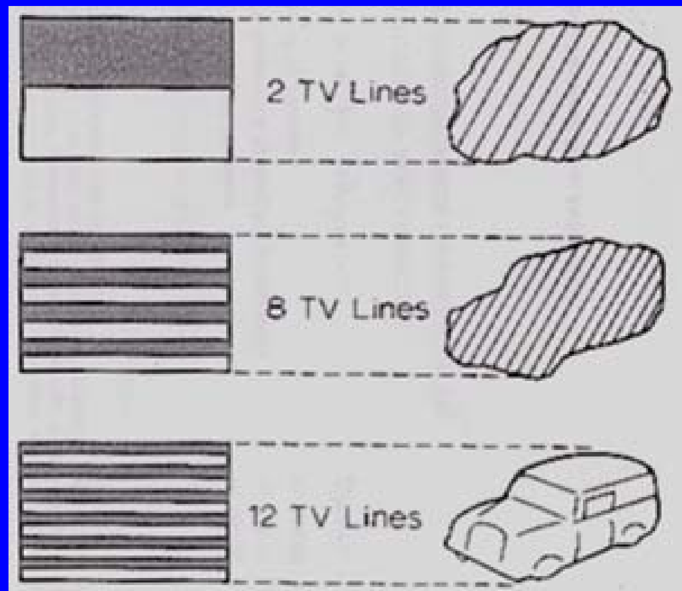
DEAL

JOHNSON'S CRITERIA

Detection

Recognition

Identification

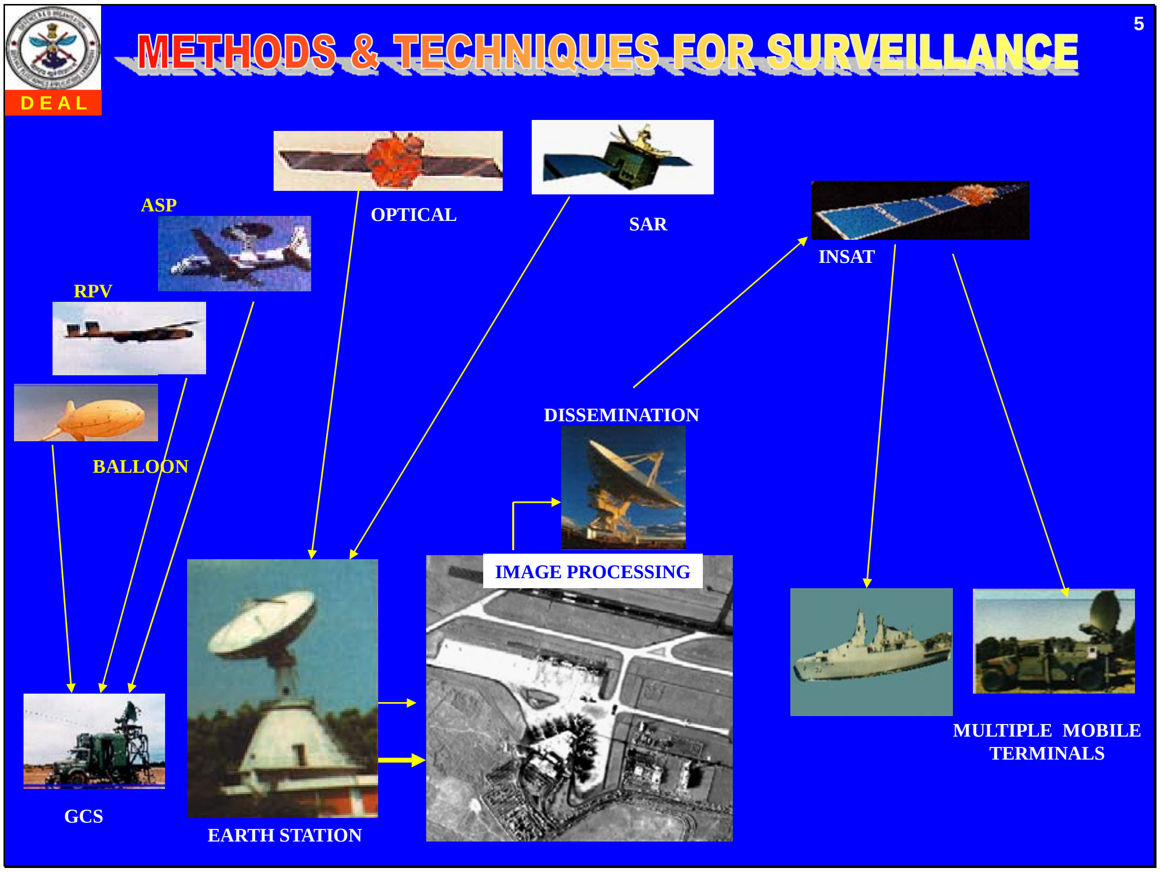


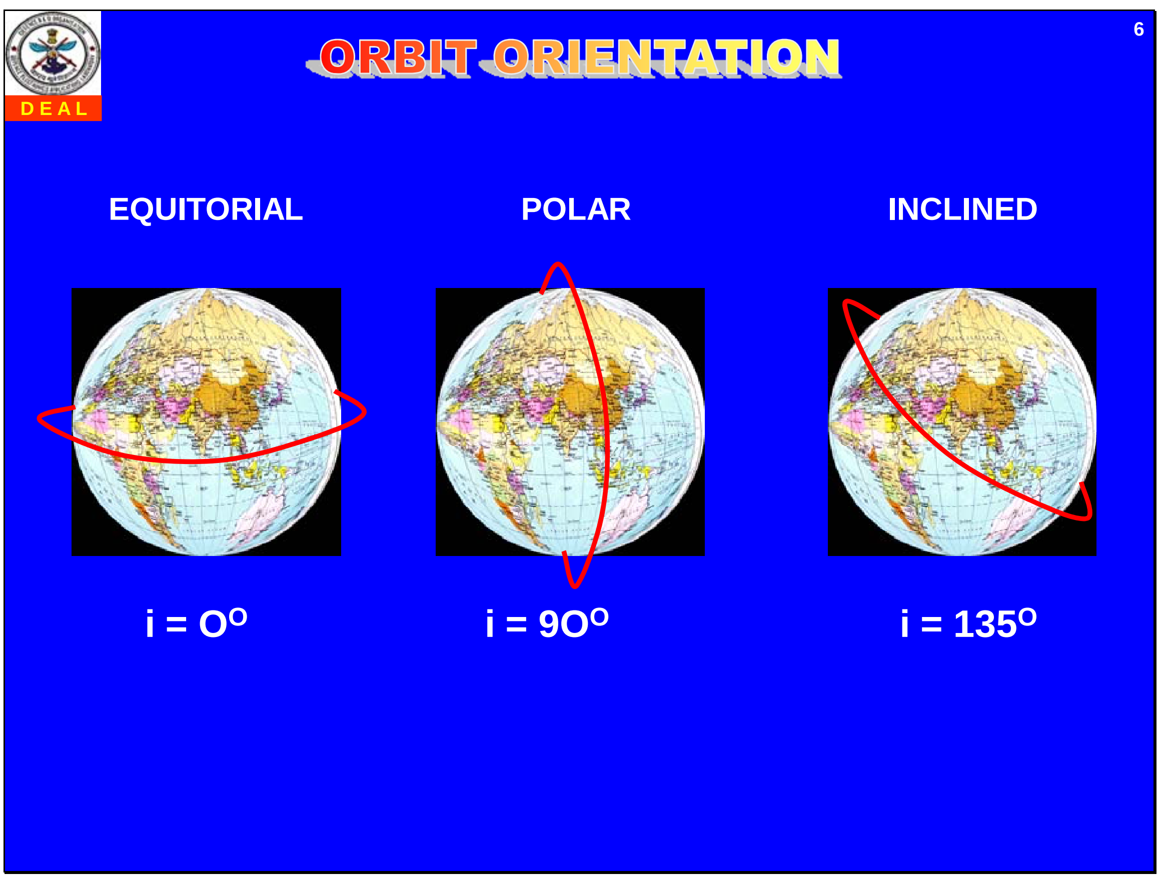
DEAL

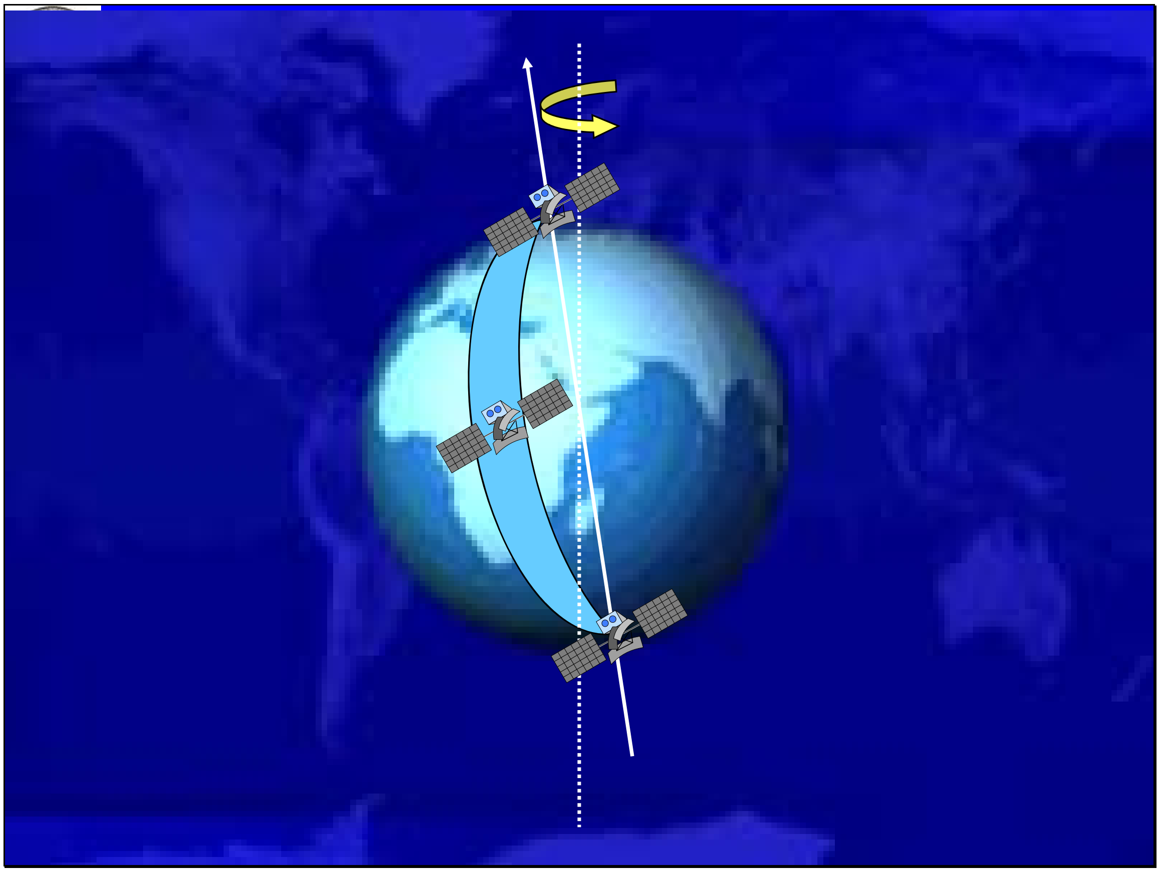
RESOLUTION

GROUND RESOLUTION (METERS) REQUIREMENT FOR MILITARY SIGNIFICANT TARGETS

TARGET	DETECTION	GENERAL ID	PRECISE ID	DESCRIPTION	TECHNICAL ANALYSIS
VEHICLES	1.5	0.6	0.3	0.06	0.045
COMM. RADIO	3	1	0.3	0.15	0.015
RADAR	3	1.5	0.3	0.15	0.015
C&C HQ.	3	1.5	1	0.15	0.09
MISSILE SITES	3	1.5	0.6	0.3	0.045
AIRCRAFT	4.5	1.5	1	0.15	0.09
AIRFIELD FACILITIES	6	4.5	3	0.3	0.15
BRIDGES	6	4.5	1.5	1	0.3
TROOP UNITS	6	2	1.2	0.3	0.15
ROADS	6-9	6	1.8	0.6	0.4
SURFACE SHIPS	7.5-15	4.5	0.6	0.3	0.045
LANDING BEACHES	15-30	4.5	3	1.5	0.15
RAIL ROAD YARDS	15-30	15	6	1.5	0.4
PORTS	30	15	6	3	0.3
URBAN AREAS	60	30	3	3	0.75
TERRAIN FEATURES		90	4.5	1.5	0.75

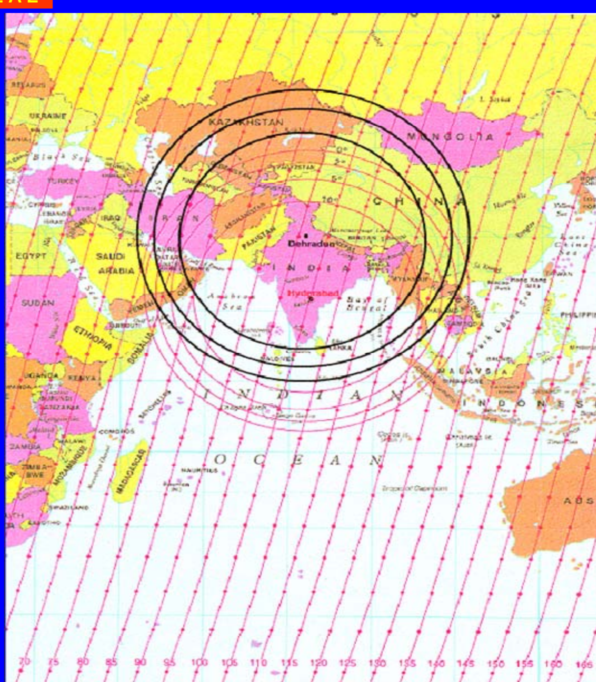

5
DEAL
METHODS & TECHNIQUES FOR SURVEILLANCE
OPTICAL
SAR
ASP
INSAT
RPV
DISSEMINATION
BALLOON
IMAGE PROCESSING
MULTIPLE MOBILE TERMINALS
GCS
EARTH STATION


6
DEAL
ORBIT ORIENTATION
EQUITORIAL
POLAR
INCLINED
i = O^O
i = 9O^O
i = 135^O



DRDO EARTH STATION

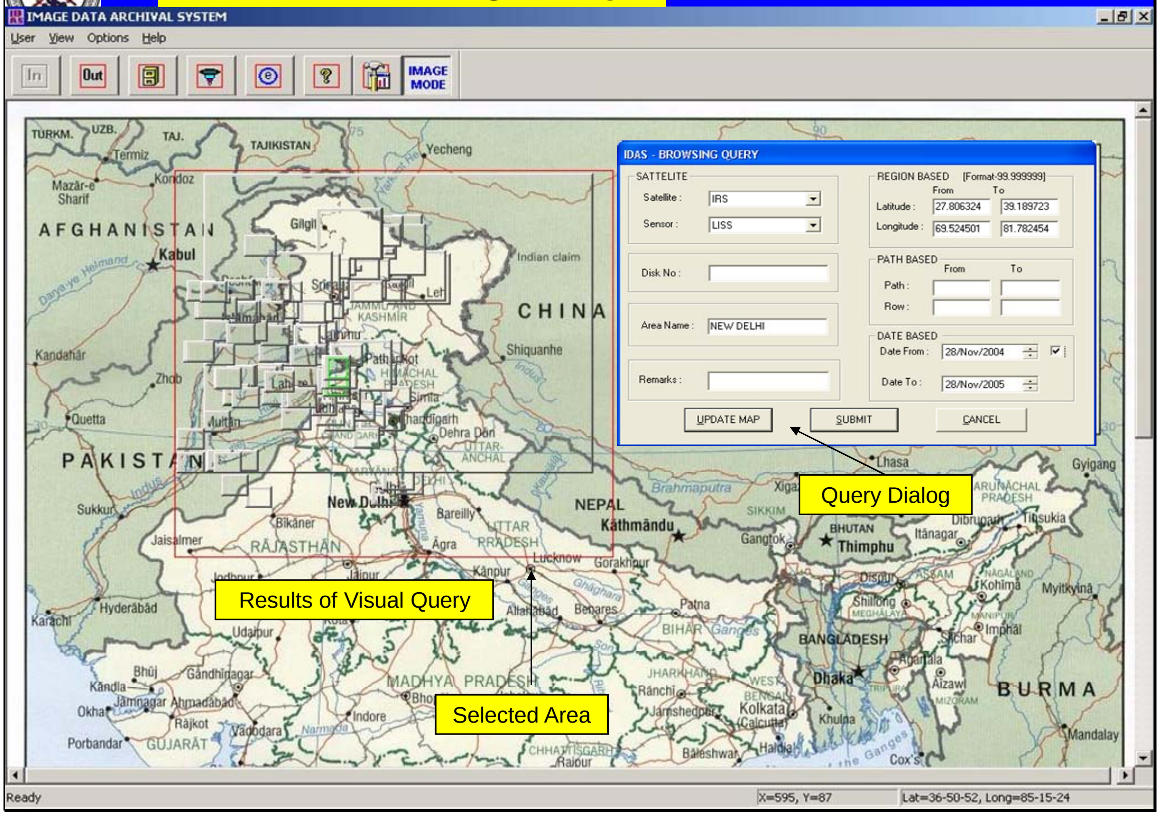
DEAL



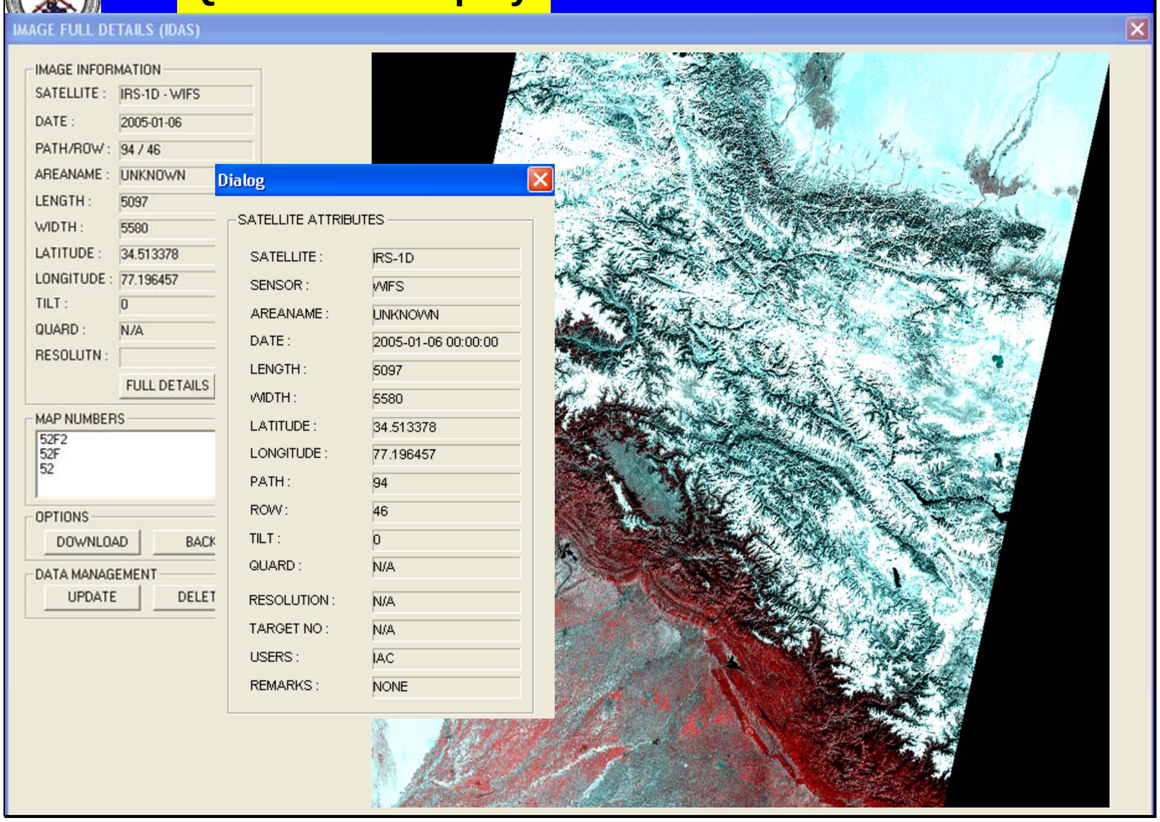
COVERAGE OF DESSI

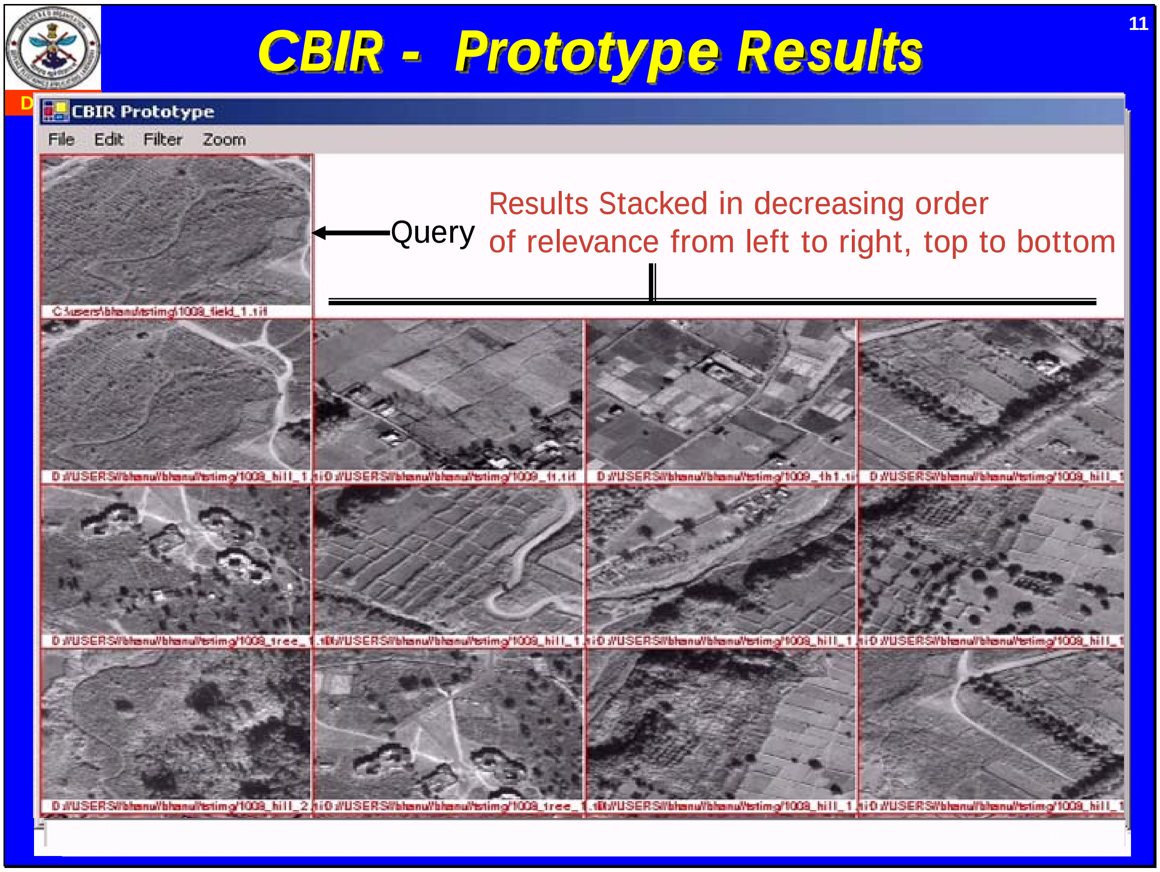
* COVERAGE RADIUS – 2500 KM
* LOCATION & HEIGHT ADVANTAGE 350 KM
* REVISIT 3/5 DAYS
* RESOLUTION
  PAN – 5.8 M
  LISS – 23.5 M
* SWATH
  PAN – 70 KM
  LISS – 141 KM
* REAL TIME IMAGE GENERATION & DISSEMINATION
* DIGITAL LINEAR TAPE (DLT) ARCHIVAL 35 GB
* OPERATION SOFTWARE BASED
* MULTIPLE SCHEDULING OF SATELLITES

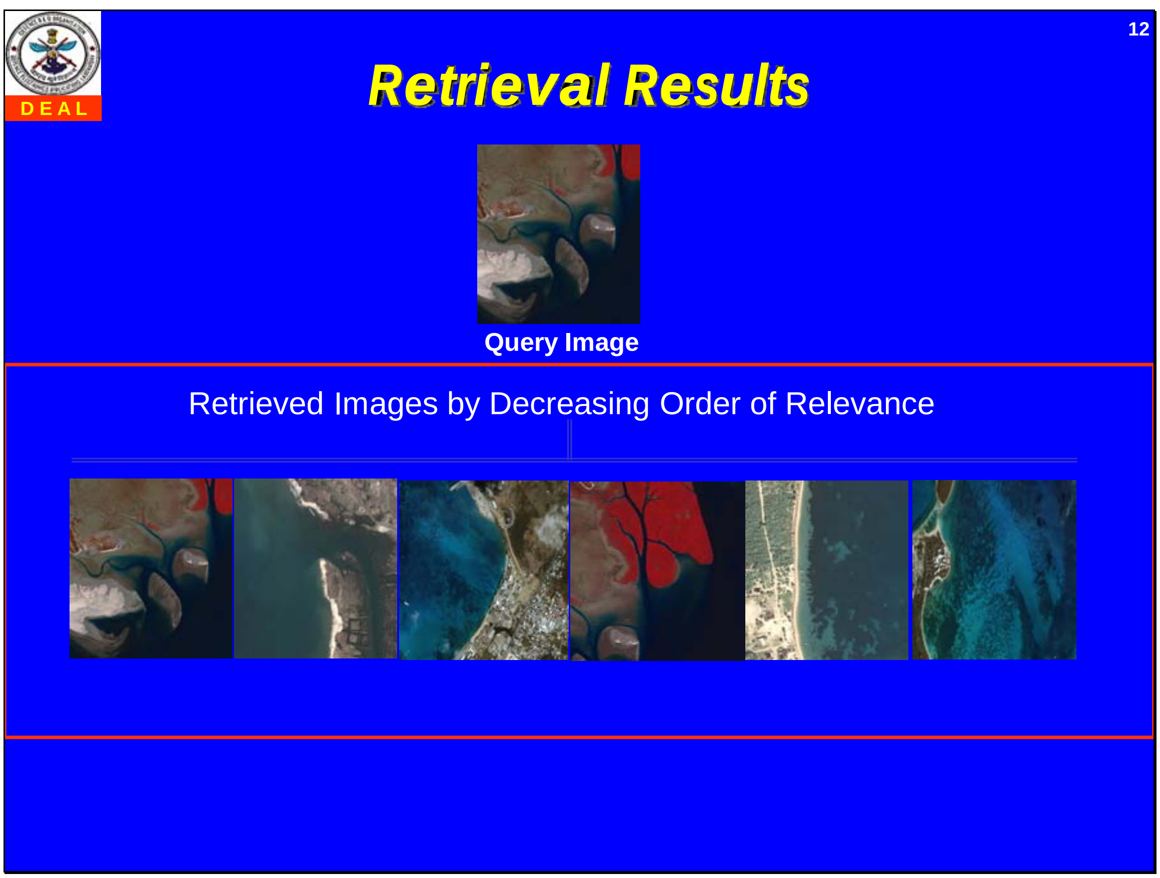
Archival Browsing Query



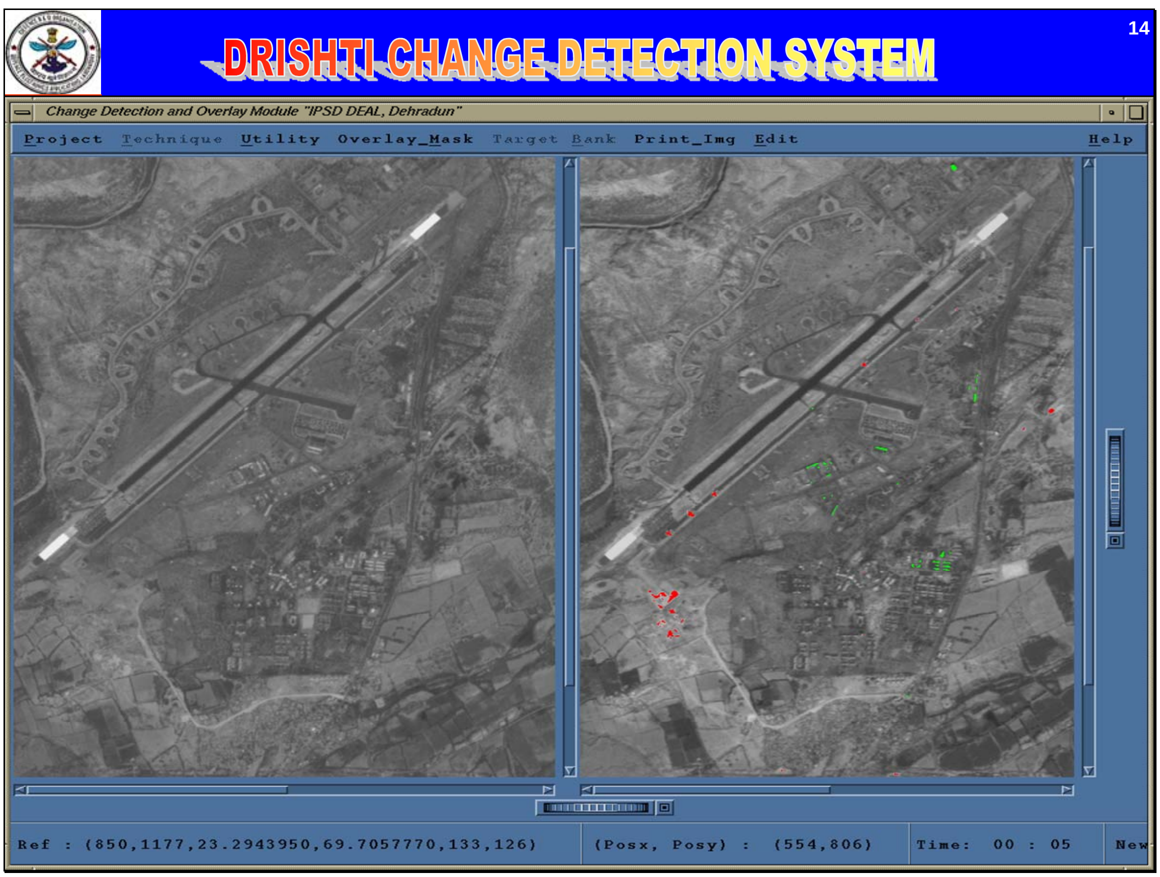
Quick look Display




11
CBIR - Prototype Results
CBIR Prototype
File Edit Filter Zoom
Query
Results Stacked in decreasing order
of relevance from left to right, top to bottom

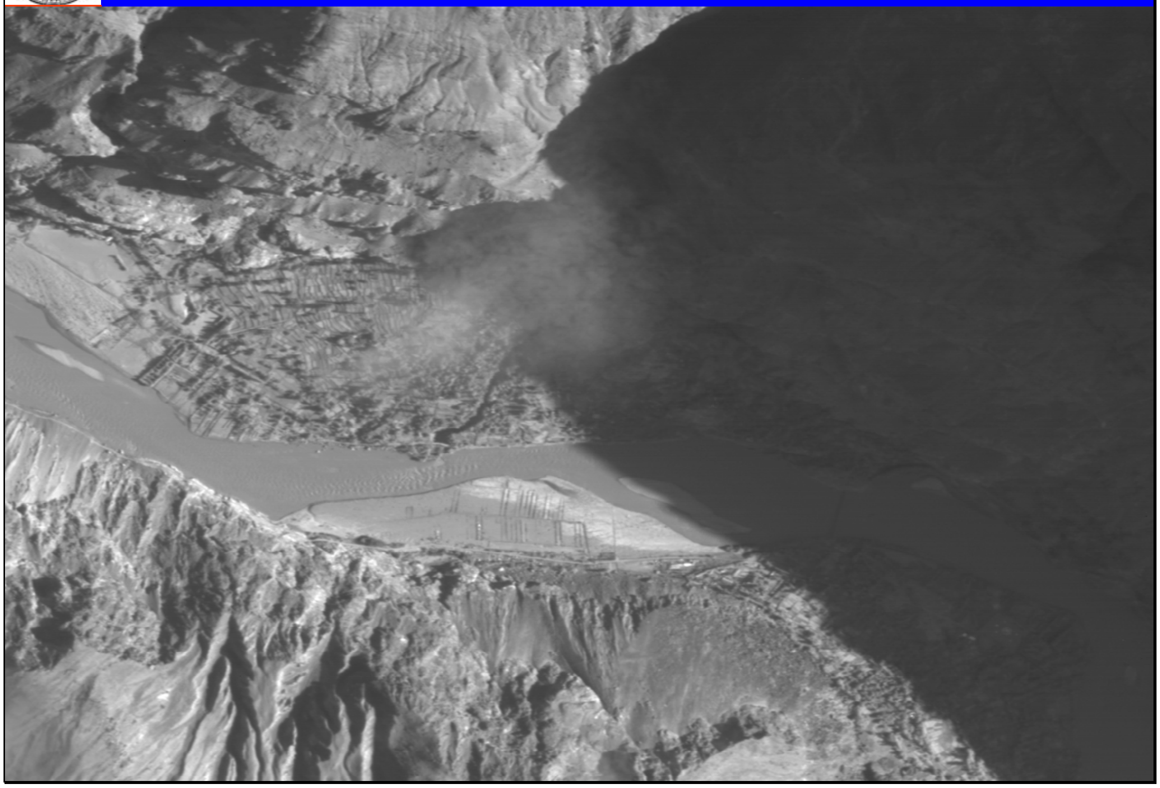

12
DEAL
Retrieval Results
Query Image
Retrieved Images by Decreasing Order of Relevance


13
DRISHTI CHANGE DETECTION SYSTEM
Change Detection and Overlay Module "IPSD DEAL, Dehradun"
Project Technique Utility Overlay_Mask Target Bank Print_Img Edit Help
Ref : (695,1249,23.3004400,69.7063600,82,82)
(Posx, Posy) : (554,806)
Time: 00 : 05


14
DRISHTI CHANGE DETECTION SYSTEM
Change Detection and Overlay Module "IPSD DEAL, Dehradun"
Project Technique Utility Overlay_Mask Target Bank Print_Img Edit Help
Ref : (850,1177,23.2943950,69.7057770,133,126)
(Posx, Posy) : (554,806)
Time: 00 : 05

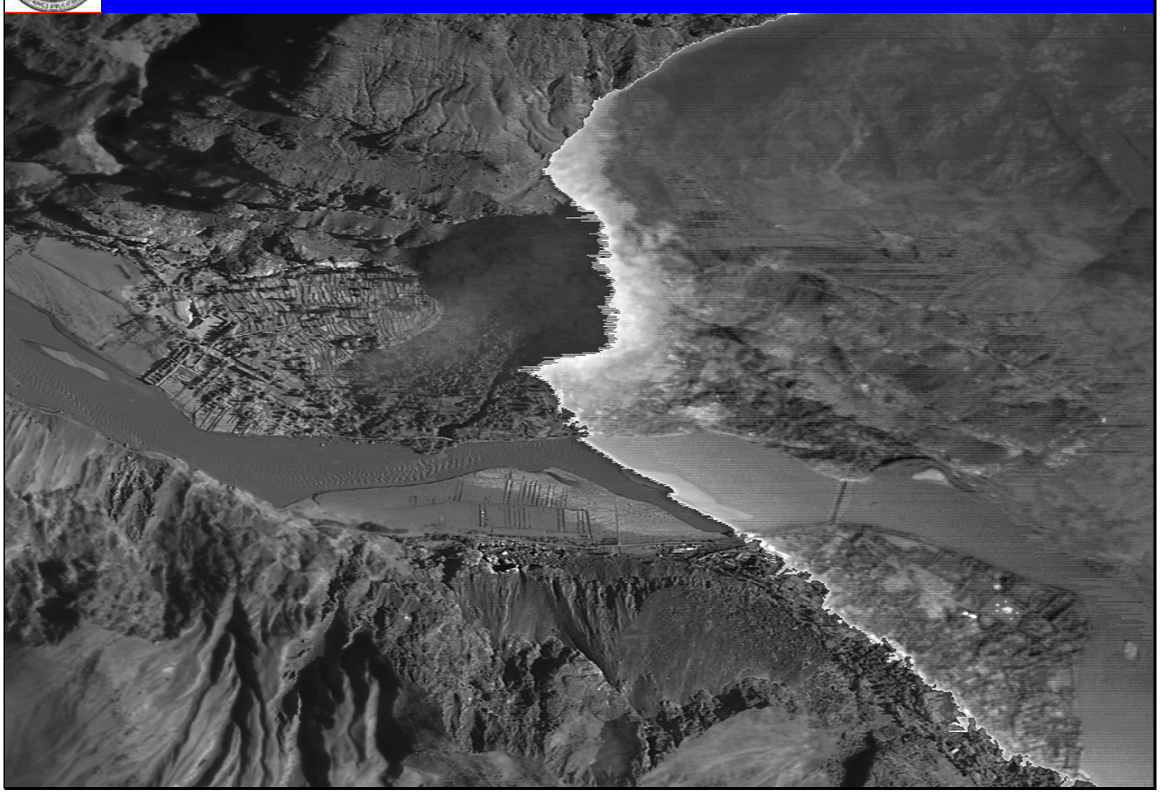
15

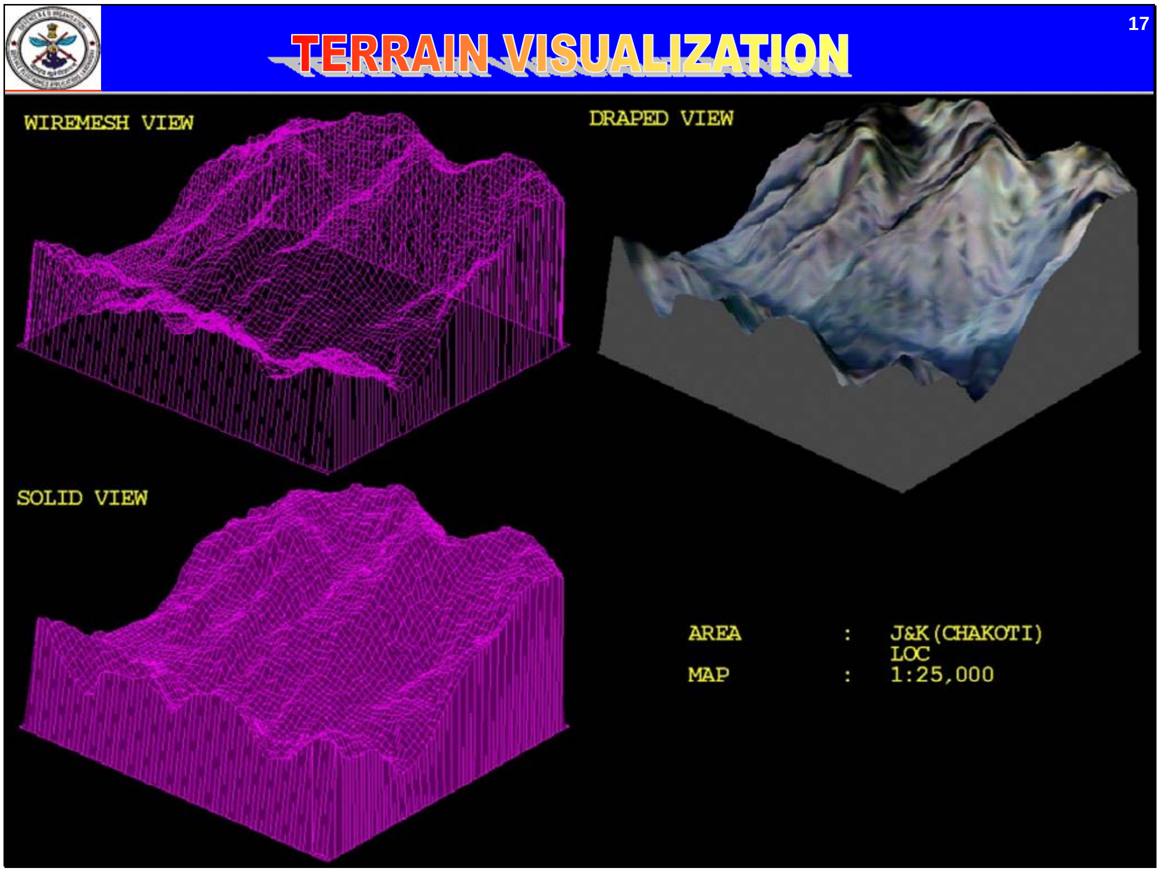
RAW IMAGE OF PIUN

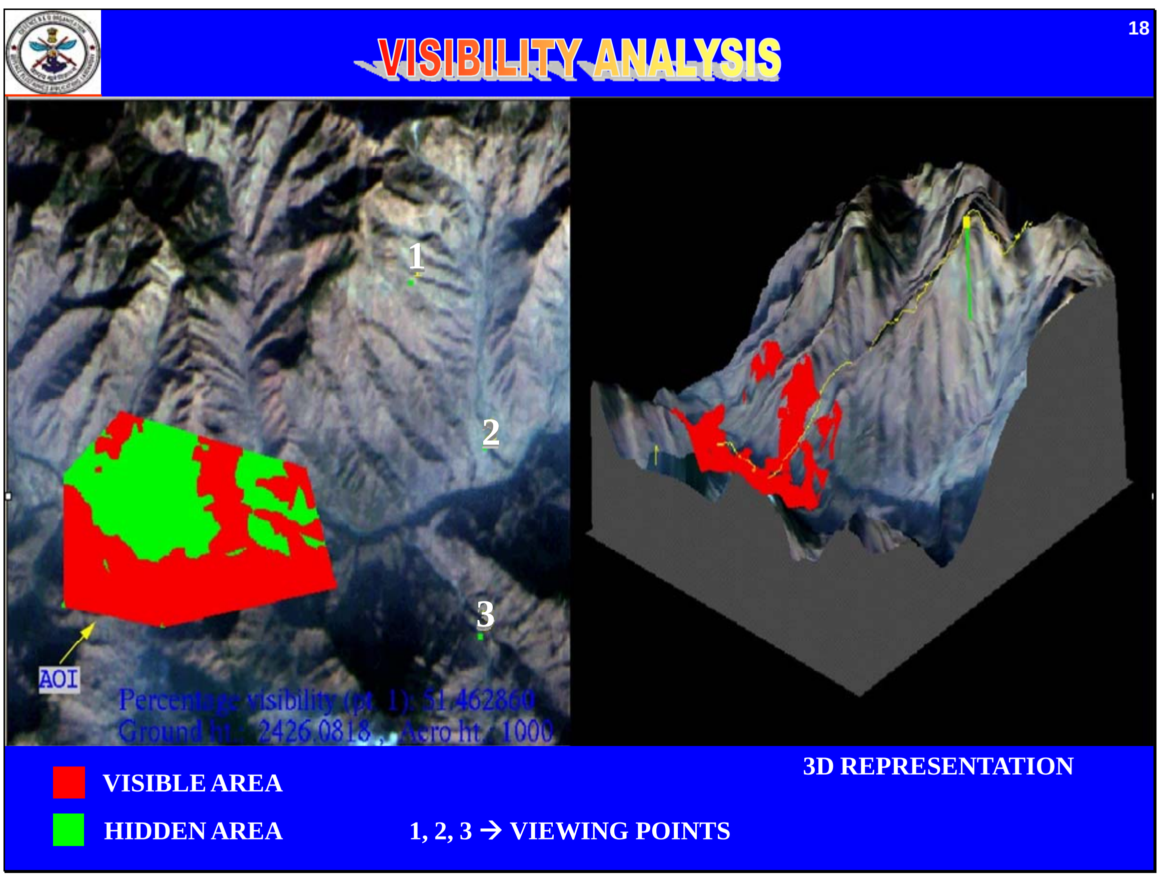


16

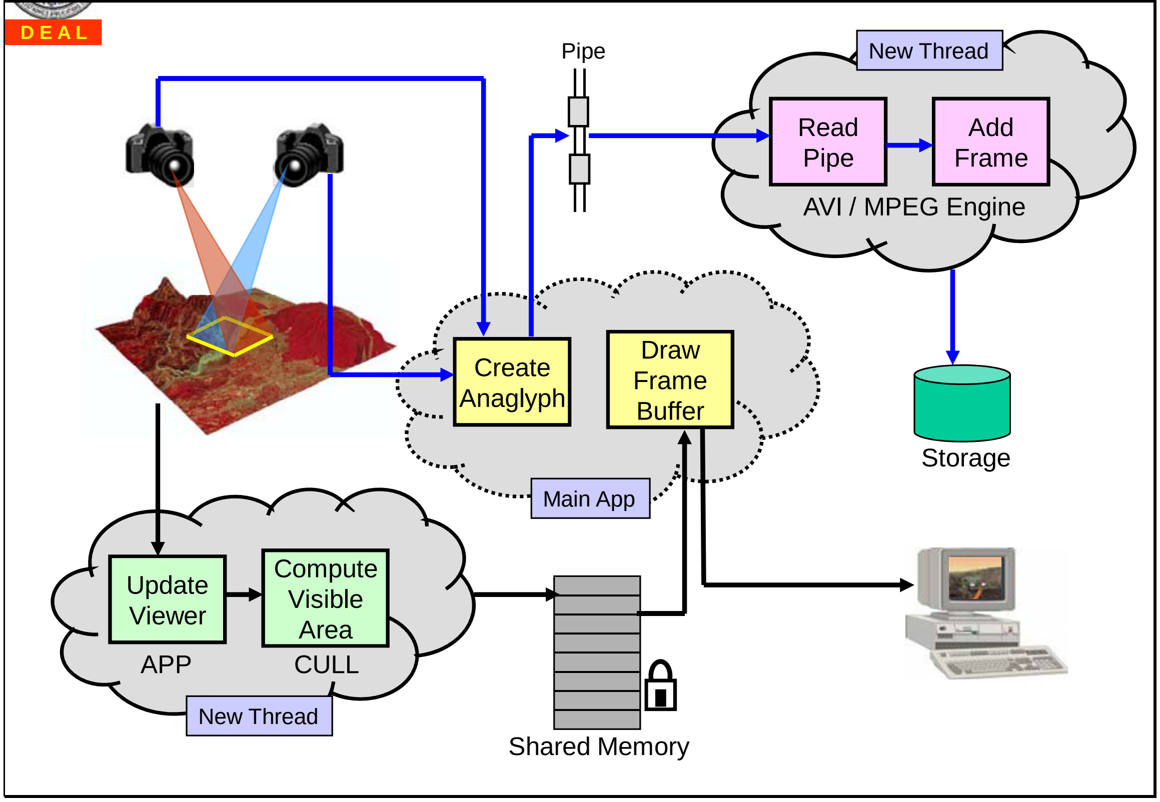
PROCESSED IMAGE OF PIUN



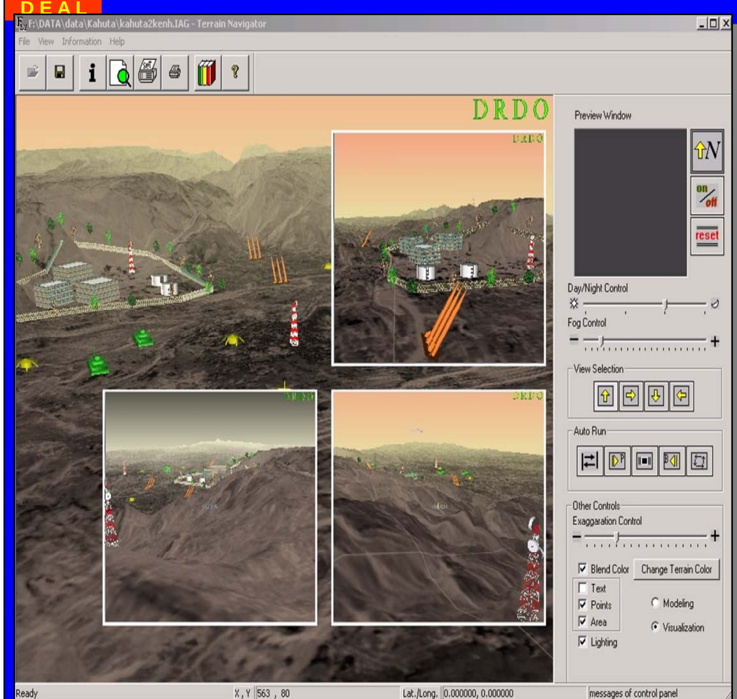

17
TERRAIN VISUALIZATION
WIREMESH VIEW
DRAPED VIEW
SOLID VIEW
AREA : J&K (CHAKOTI) LOC
MAP : 1:25,000


18
VISIBILITY ANALYSIS
1
2
3
AOI
Percentage visibility (pt. 1): 51.462860
Ground ht.: 2426.0818 , Aero ht.: 1000
VISIBLE AREA
HIDDEN AREA
1, 2, 3 → VIEWING POINTS
3D REPRESENTATION

Virtual Fly – Use of Paging & Stereoscopic Movie



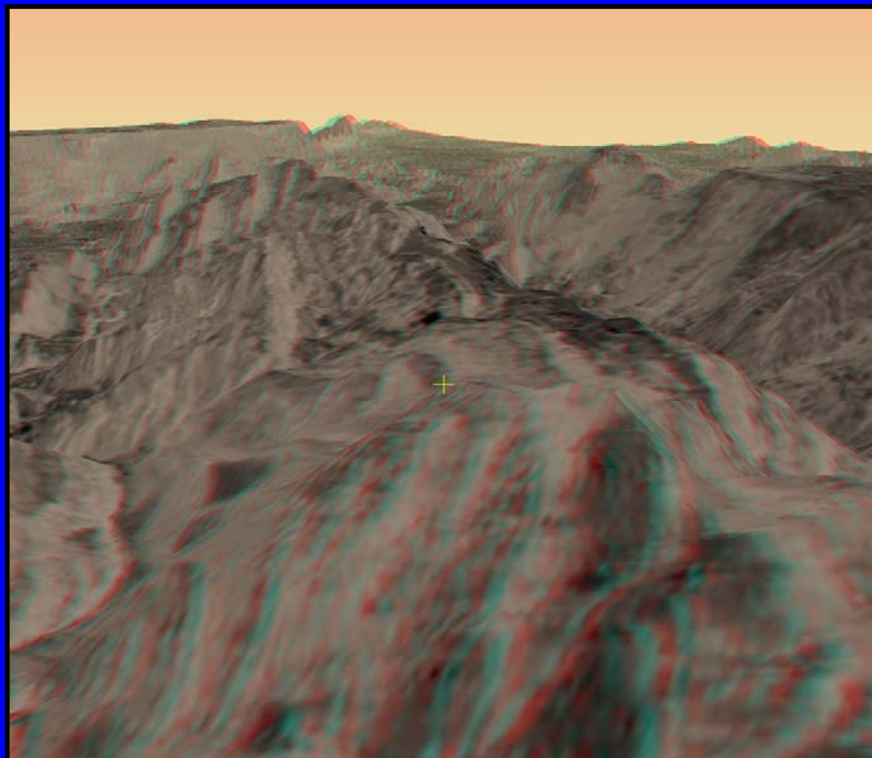
Result – Virtual Fly Video



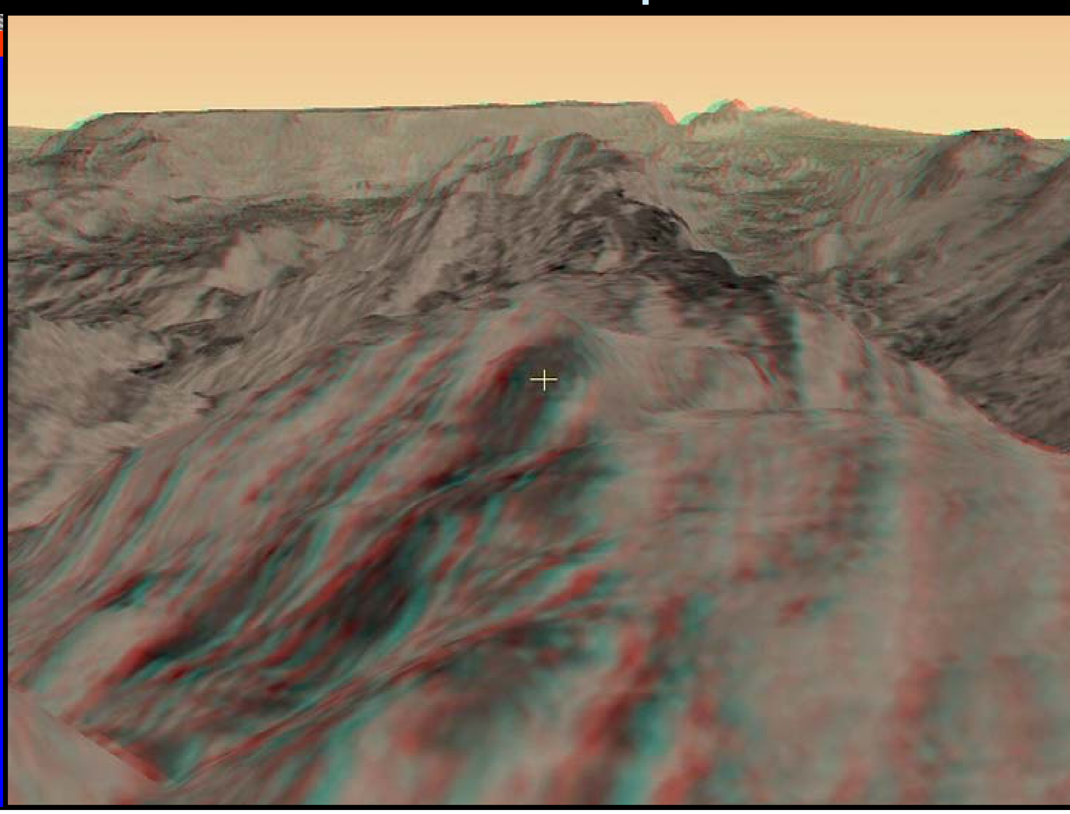
Features

- Fast & Efficient Rendering
- Virtual Paging Supported
- Support DT-1, DT-2, GeoTiff
- Auto/ Manual mode navigation
- Vector layer overlay
- Inline 3D military object library
- Movie store engine for AVI/ MPEG
- Anaglyph color image & video
- Multiple view selection
- Height Exaggeration Control
- Auto Enhancement
- Texture Blending
- Frame capture
- Atmospheric effect controls (Sky, Horizon, Fog etc.)
- light modeling

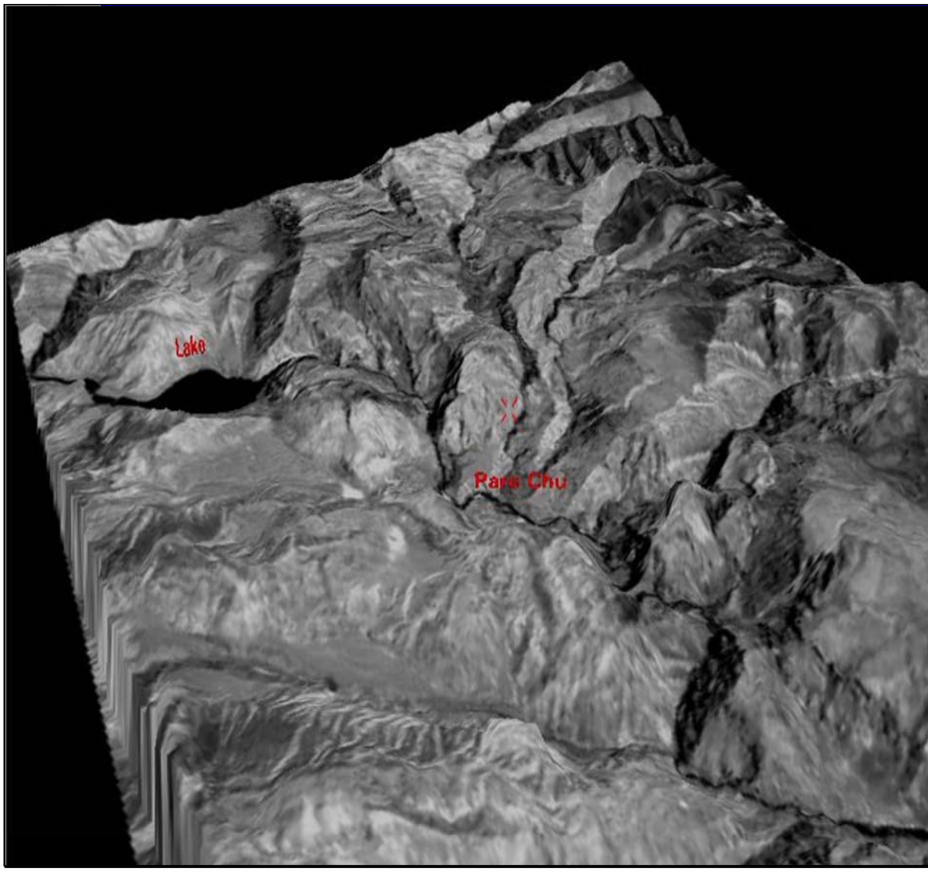
Result - Anaglyph Image



Result - Stereoscopic Video

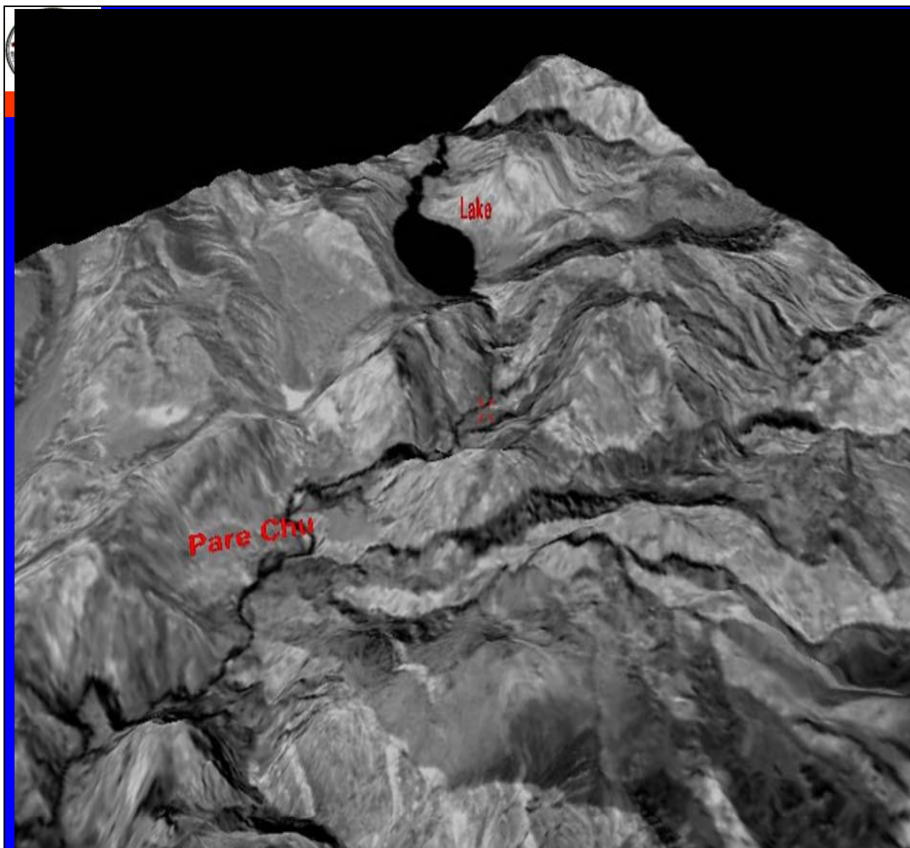


23



AERIAL VIEW OF THE TERRAIN AFTER THE FORMATION OF LAKE

24

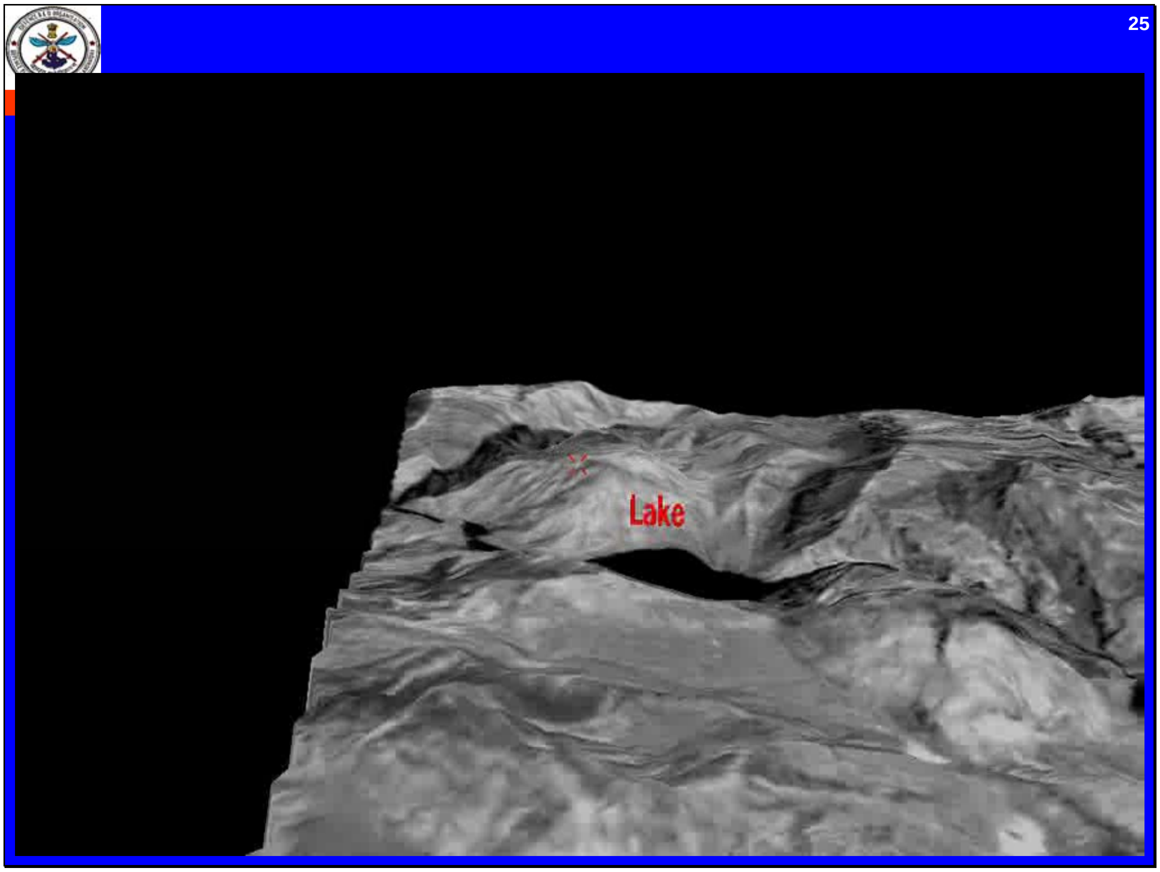


AREA OF LAKE

188 HECTARES

VOLUME OF WATER

140 MILLION CUBIC METERS


25
Lake

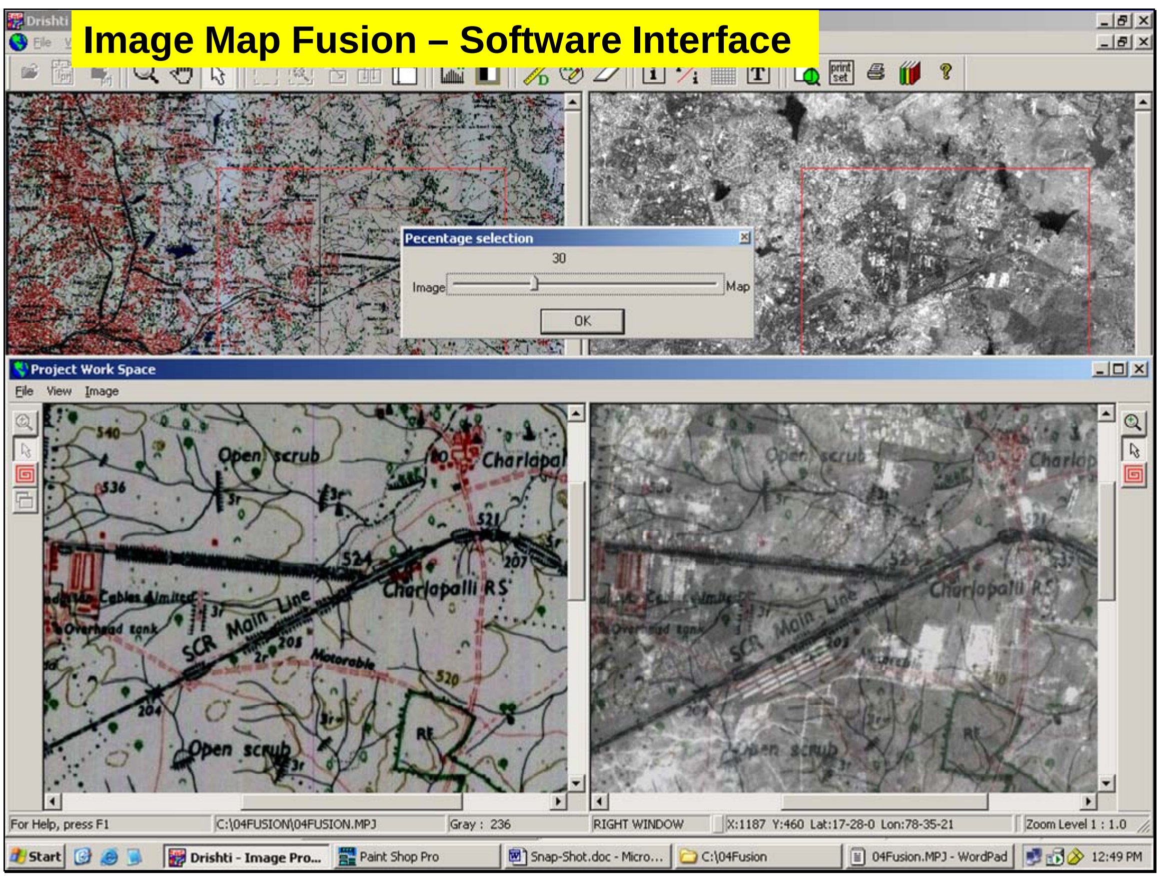
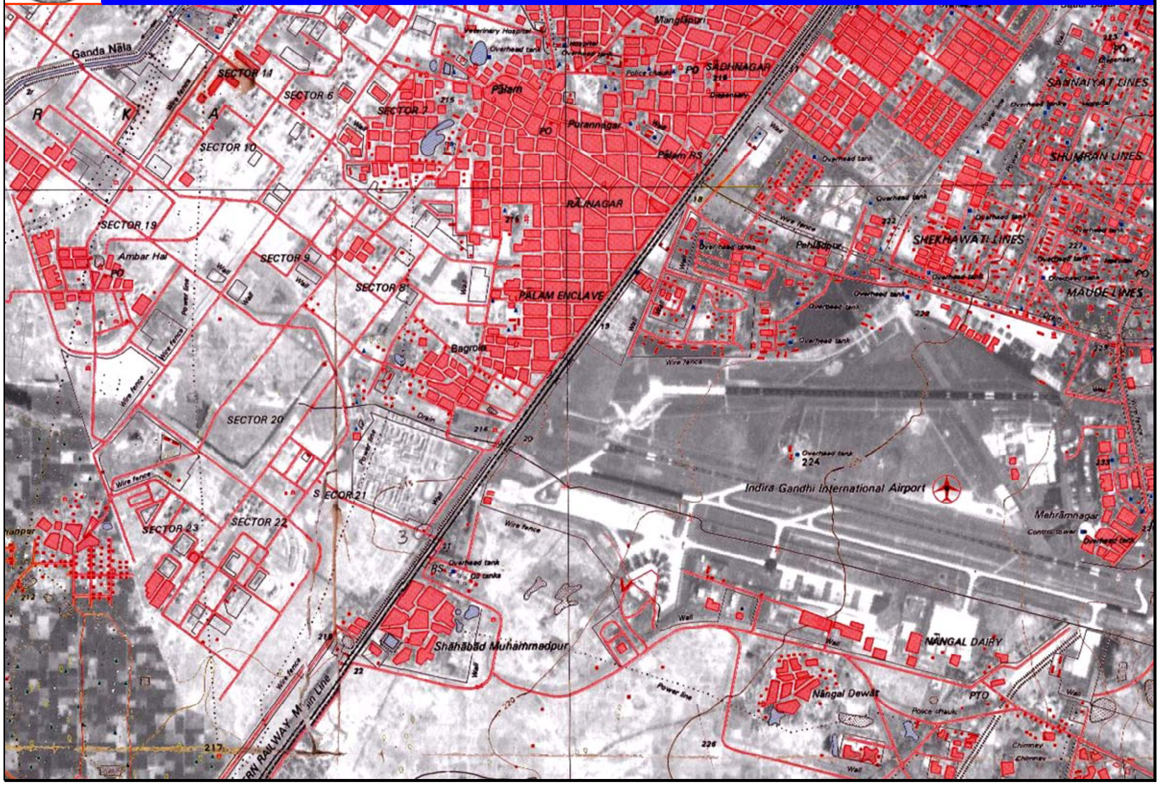


Image Map Fusion – Software Interface
Pecentage selection
30
Image
Map
OK
Project Work Space
Open scrub
Charlopal
Charlapalli RS
SCR Main Line
Cables Limited
Overhead tank
Motorable
For Help, press F1
C:\04FUSION\04FUSION.MPJ
Gray : 236
RIGHT WINDOW
X:1187 Y:460 Lat:17-28-0 Lon:78-35-21
Zoom Level 1 : 1.0

IMAGE MAP GENERATION

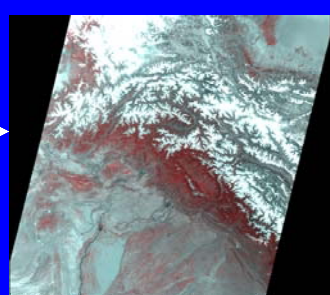


DEAL

Image Mosaicking

CANDIDATE IMAGES

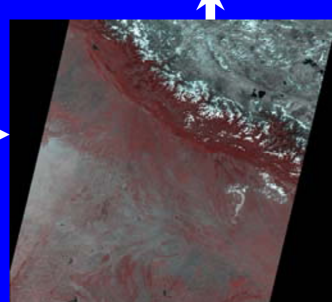
VISUALIZATION

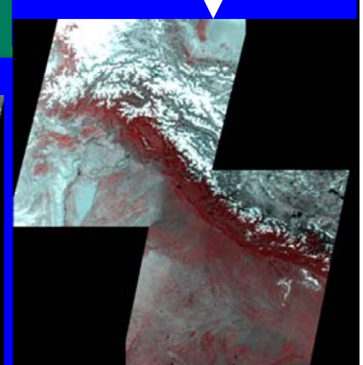


STITCHING (GEO. ALIGNMENT)

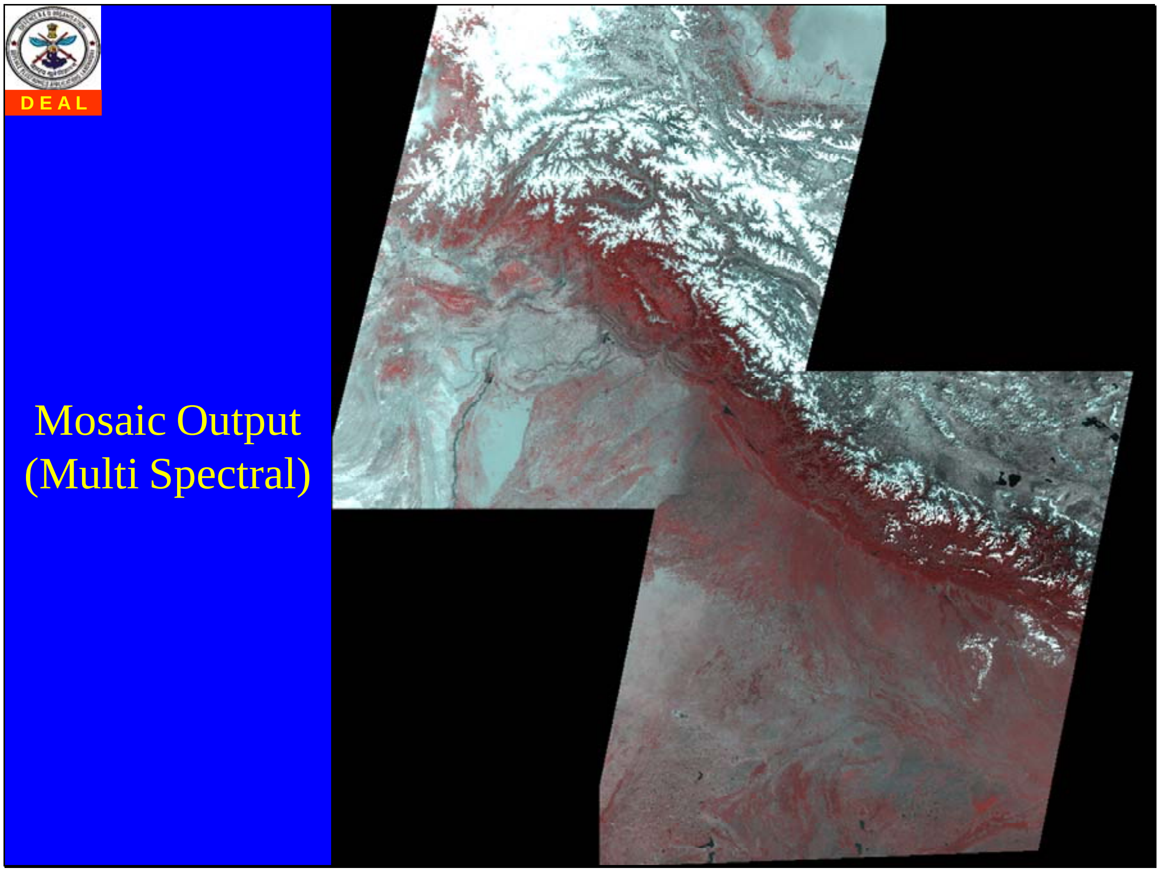
RADIOMETRIC BALANCING

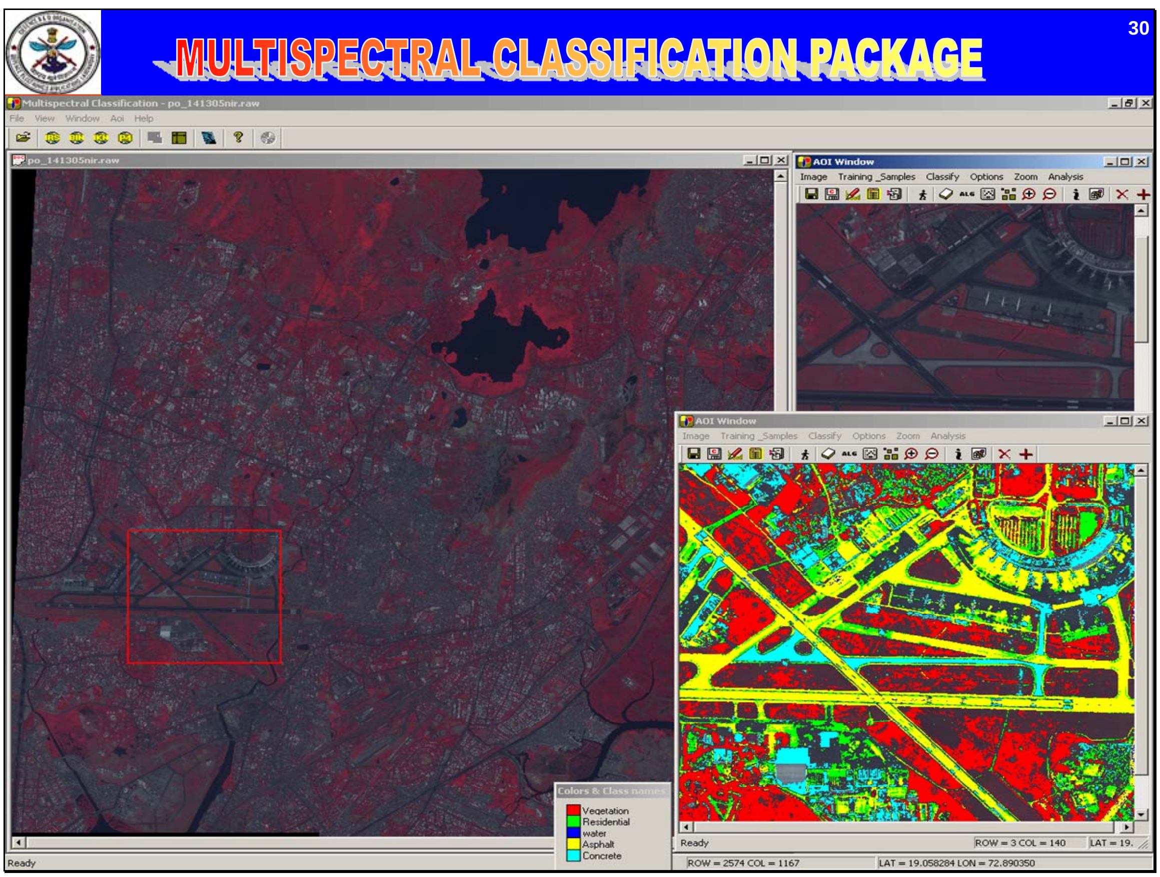
IMAGE BLENDING





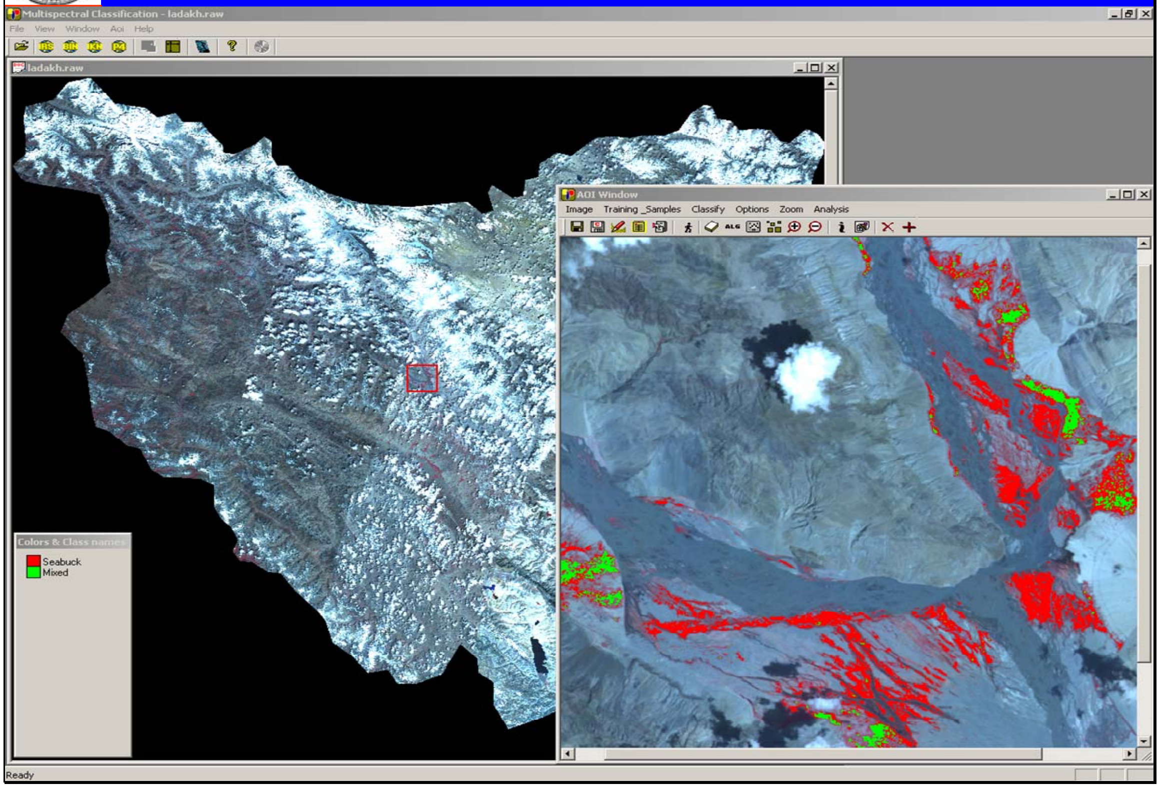
- ✓ Interface with Archival
- ✓ Tiling of Images
- ✓ Multiple Scene Mosaicking
- ✓ Generation of Mosaick Preview
- ✓ WiFS, LISS & PAN FULL SCENE
- ✓ Overlap & Non Overlap
- ✓ Use of Geographic Information


DEAL
Mosaic Output
(Multi Spectral)


MULTISPECTRAL CLASSIFICATION PACKAGE
30
Multispectral Classification - po_141305nir.raw
AOI Window
Image Training _Samples Classify Options Zoom Analysis
Colors & Class names
Vegetation
Residential
water
Asphalt
Concrete
Ready
ROW = 2574 COL = 1167
LAT = 19.058284 LON = 72.890350

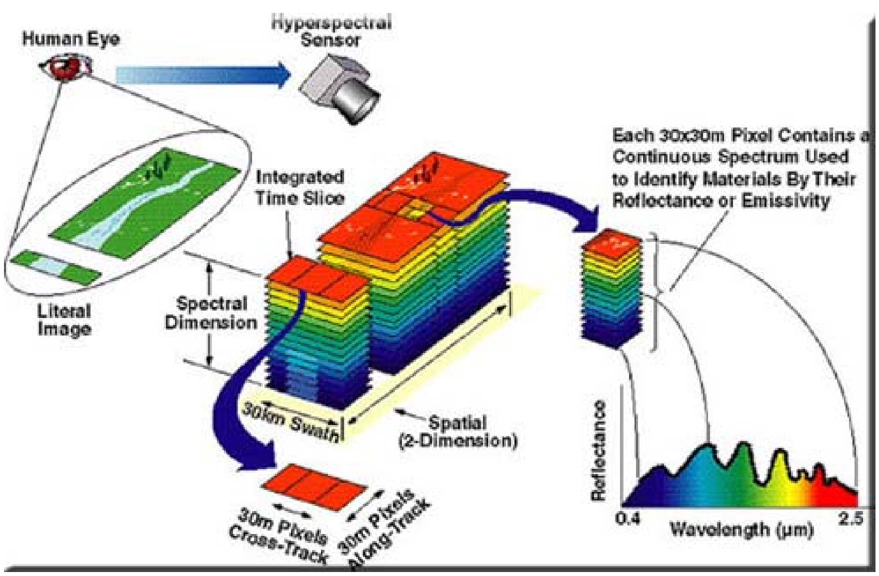
31

SEABUCKTHORN ESTIMATION



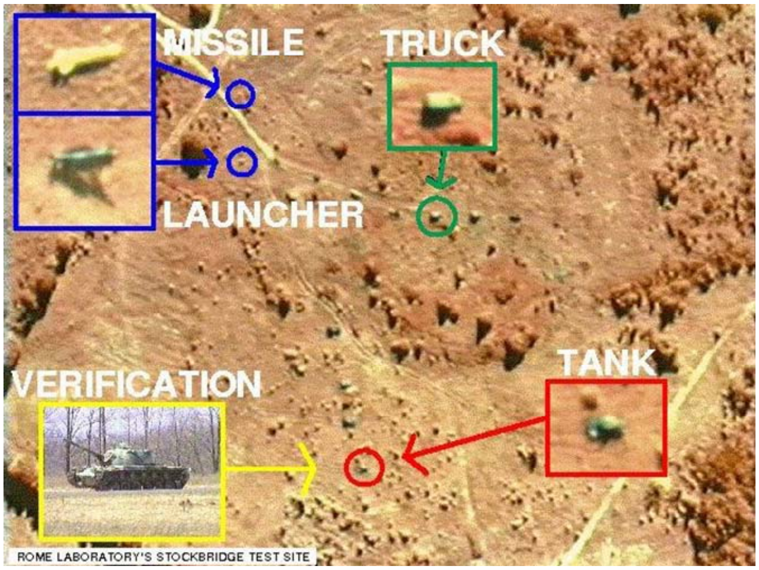
DEAL

HYPER SPECTRAL DATA PROCESSING



DEAL

HYPERSPECTRAL IMAGE

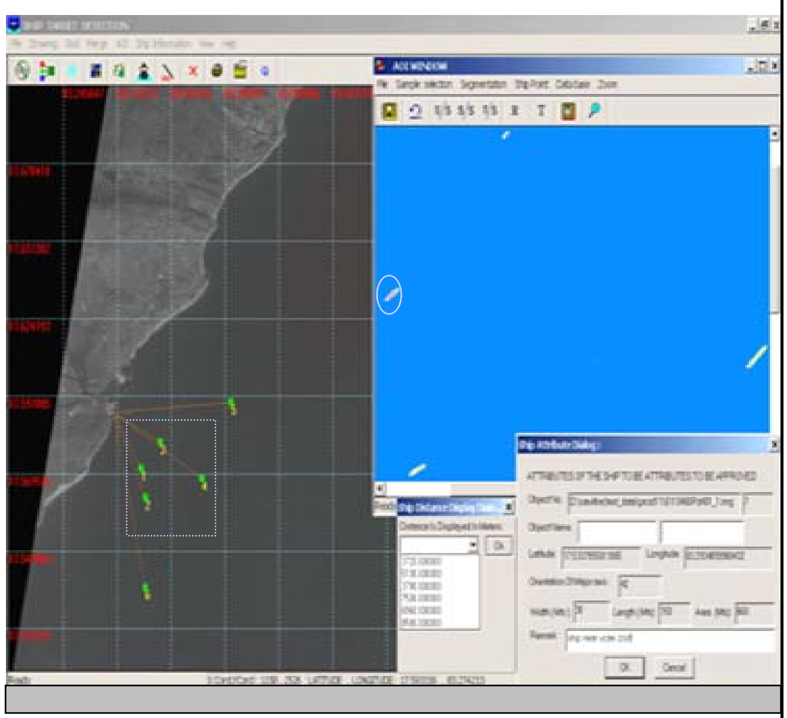


DEAL

SHIP DETECTION PACKAGE

FEATURES

- **Display and Browsing of IRS 1C/1D images in LGSOWG,Geotiff and generic binary format.**
- **Area of interest selection and Zoom facility**
- **Facility for land masking**
- **Segmentation/Classification into water and non water class**
- **highlighting candidate ship like objects**
- **Attributes Extraction and saving in file / database**
- **Report Generation**
  - **Highlighting ships on full scene**
  - **Distances from any reference point**

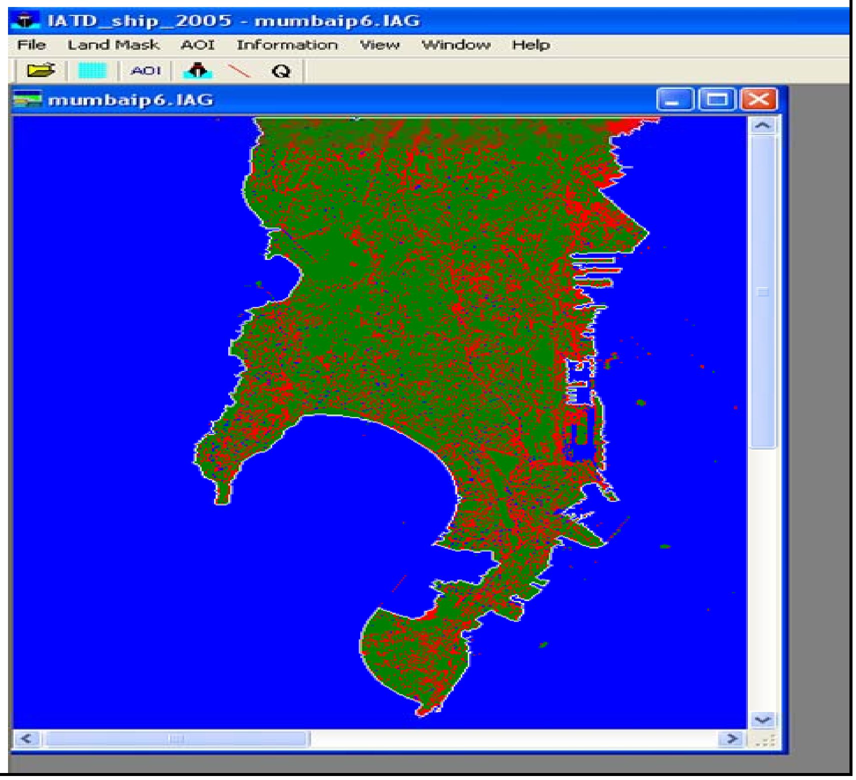


DEAL

COAST LINE DETECTION

New features

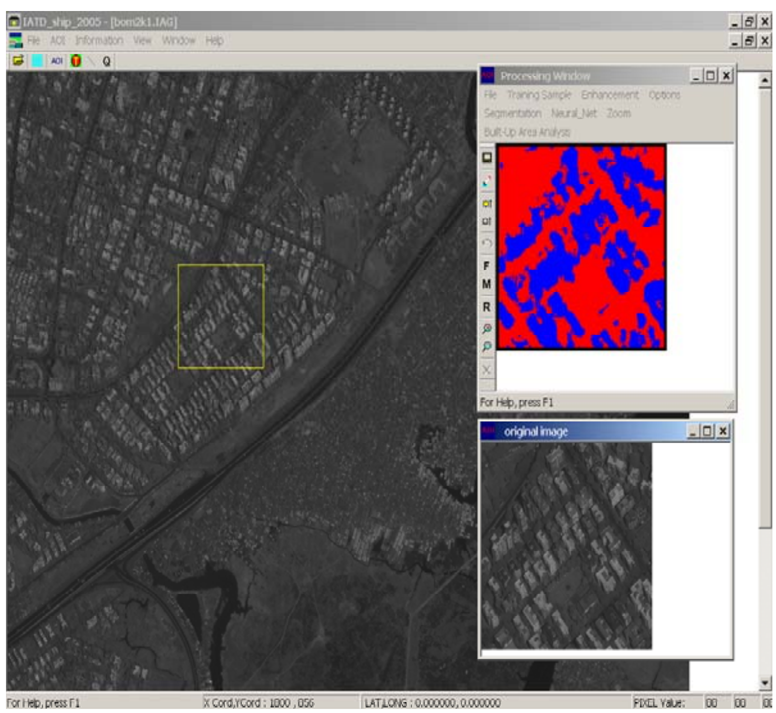
- **IRS P6 Module**
  - **Coast line detection**
  - **Ship detection**



DEAL

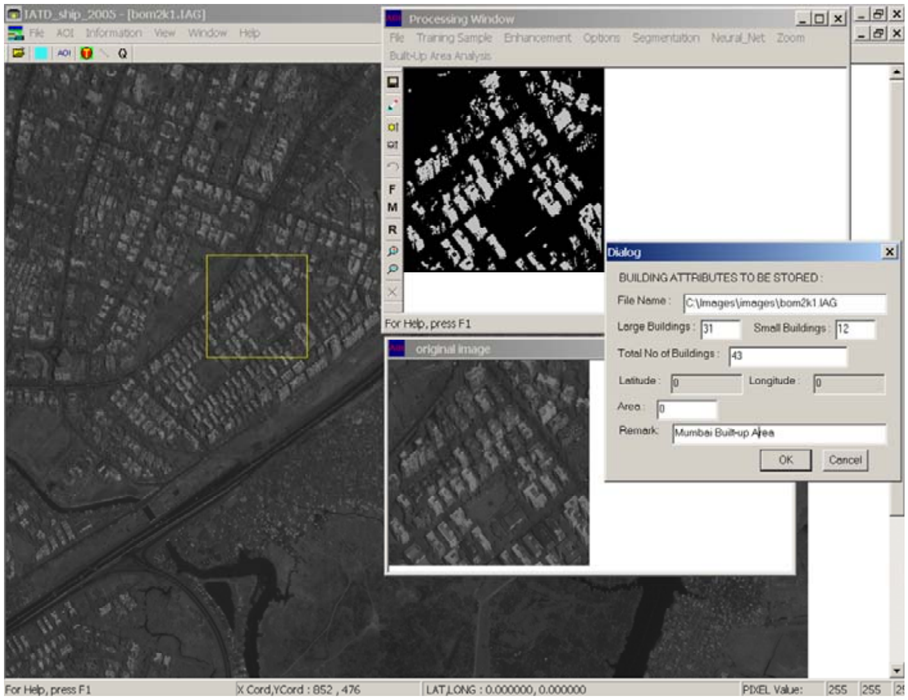
BUILT UP AREA ANALYSIS

- **Built-up area analysis**
  - **Locating built-up area**
  - **Lay out of built-up area**
  - **Buildings counts**



DEAL

BUILT UP AREA ANALYSIS

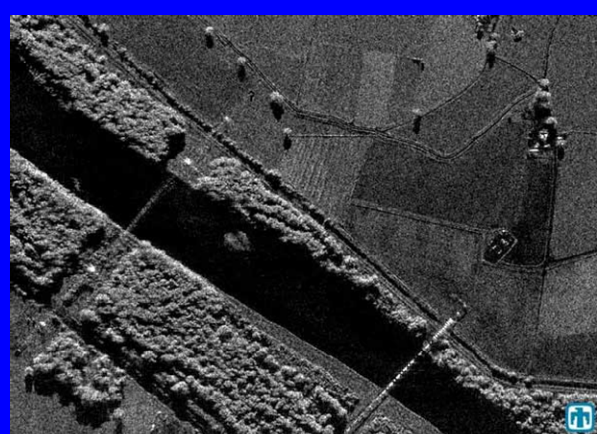


DEAL

38

FOLIAGE AND GROUND PENETRATION

Synthetic aperture radars offer the capability for penetrating materials which are optically opaque, and thus not visible by optical or IR techniques.

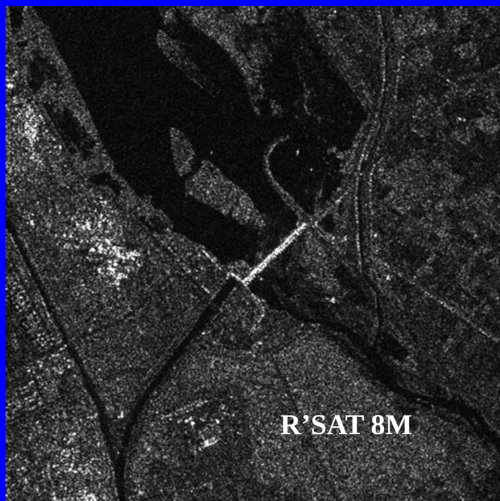


Low-frequency SAR may be used under certain conditions to penetrate foliage and even soil.

DEAL

39

FACE TO FACE WITH OPTICAL



DAM

DEAL

40

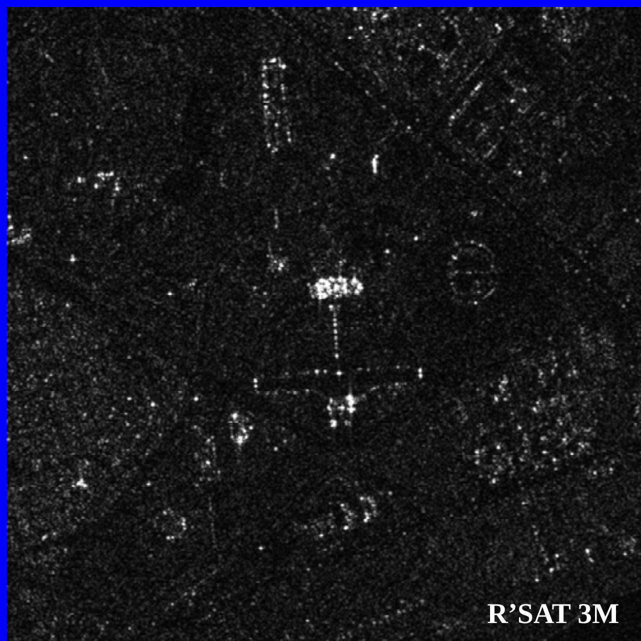
FACE TO FACE WITH OPTICAL

R'SAT 3M

IRS-PAN 6M

URBAN
AREA

FACE TO FACE WITH OPTICAL



BOUNDARY DETAILS

RECONNAISSANCE, SURVEILLANCE & TARGETING

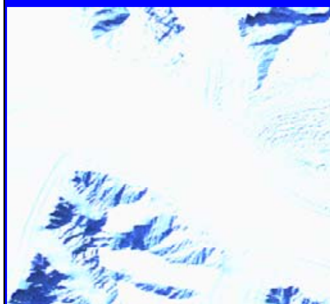
Ship/ Bridge Detection- as they act as bright reflectors over homogeneous background.

43

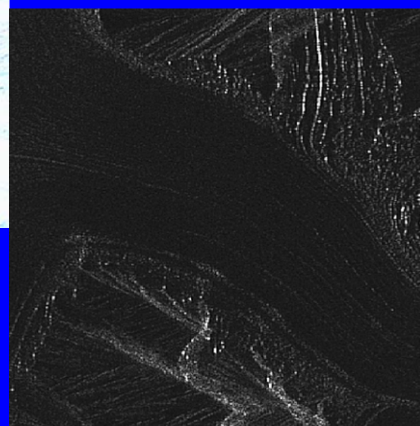
DEAL

SNOW/ICE STUDIES

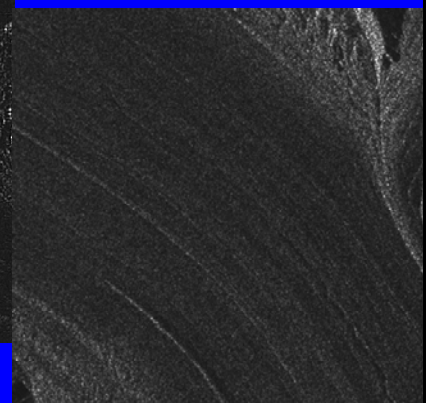
Rich in texture, hence better suited for snow/ice studies



LISS-III



ERS

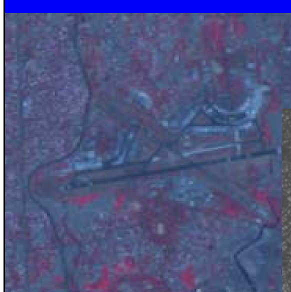


RADARSAT

44

DEAL

MULTISENSOR DATA FUSION



IRS-LISS

IRS-PAN

FUSED IMAGE

DEAL

45

MULTISENSOR DATA FUSION

RADARSAT

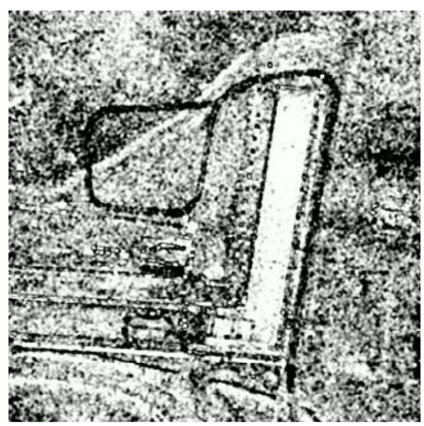
IRS PAN

FUSED IMAGE

DEAL

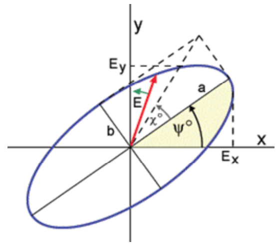
COHERENT CHANGE DETECTION

A technique known as coherent change detection offers the capability for detecting changes between imaging passes.

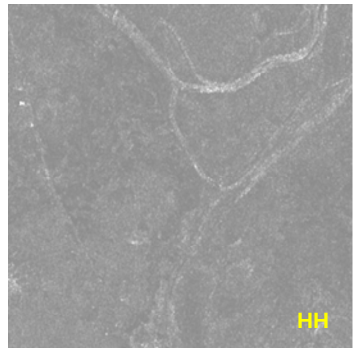


DEAL

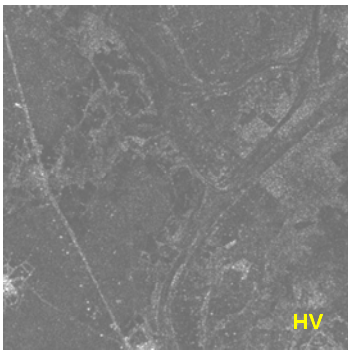
SAR-Polarimetry

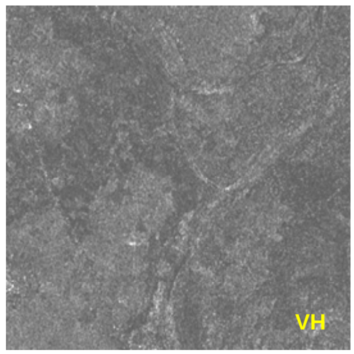


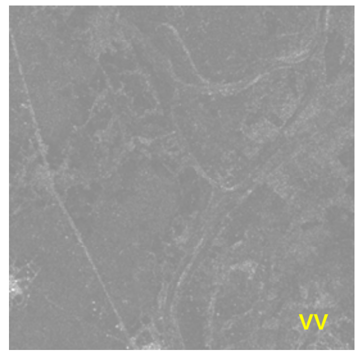
Polarization ellipse showing the orientation angle ψ and ellipticity χ , which are a function of the semi-major and semi-minor axes, a and b



Black Buck National Forest, Gujarat Area





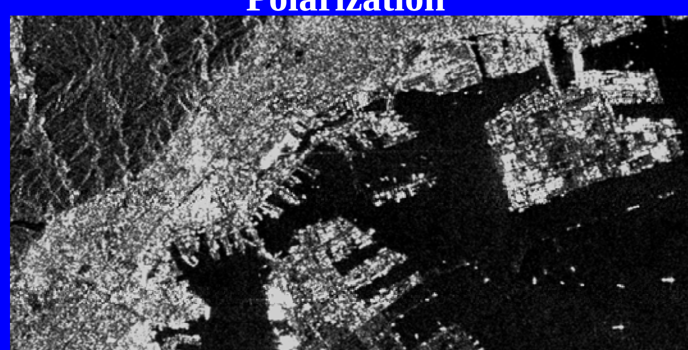


DEAL

SAR IMAGE CHARACTERISTIC

Polarization

RADARSAR-HH



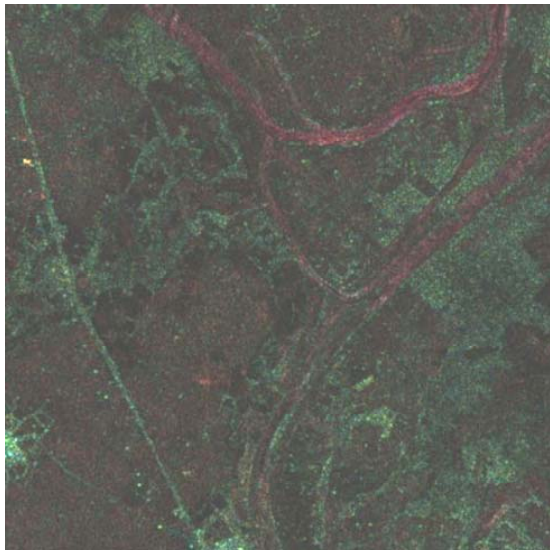
ERS-VV

SAR-Polarimetry

DEAL

Processing of Quad Polarized SAR data.

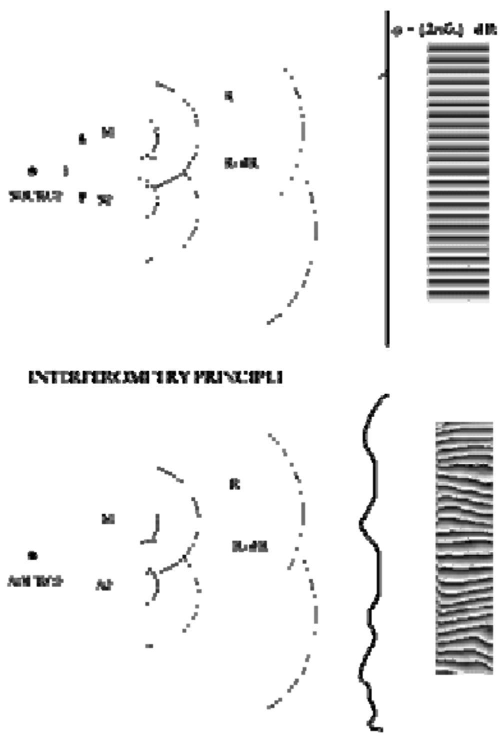
Useful in Target Detection and Identification



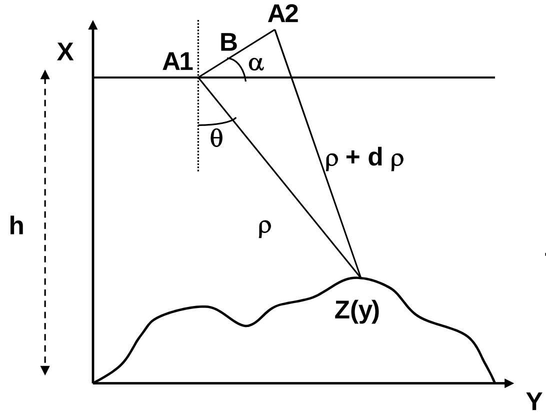
False Color Composite (HH, HV and VV Band)

DEAL

INTERFEROMETRY



INTERFEROMETRY



$$z(y) = h - \rho\cos(\theta)$$

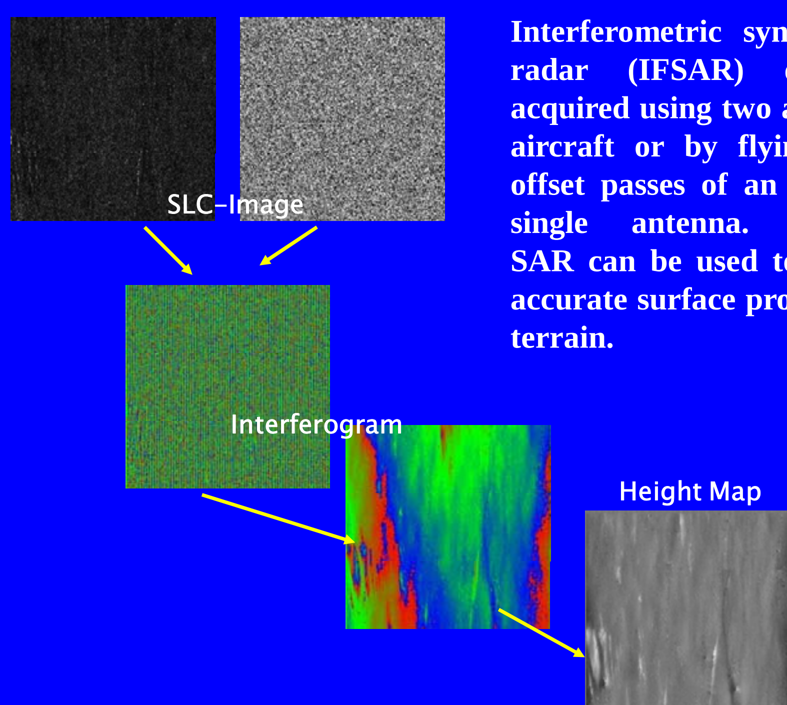
$$(\rho + d\rho)^2 = \rho^2 + B^2 + 2\rho B\sin(\alpha - \theta)$$

The phase difference ϕ is given by

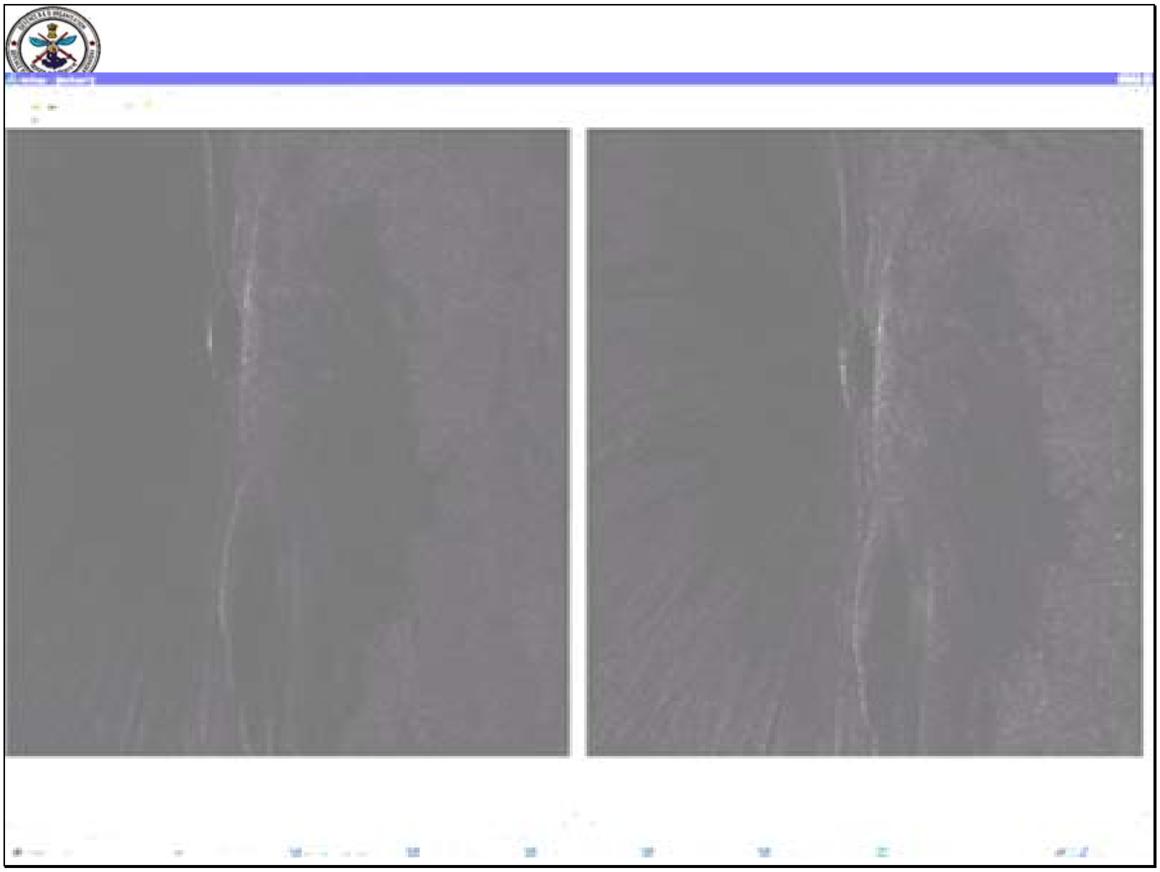
$$\phi = \frac{2\pi * d\rho}{\lambda}$$

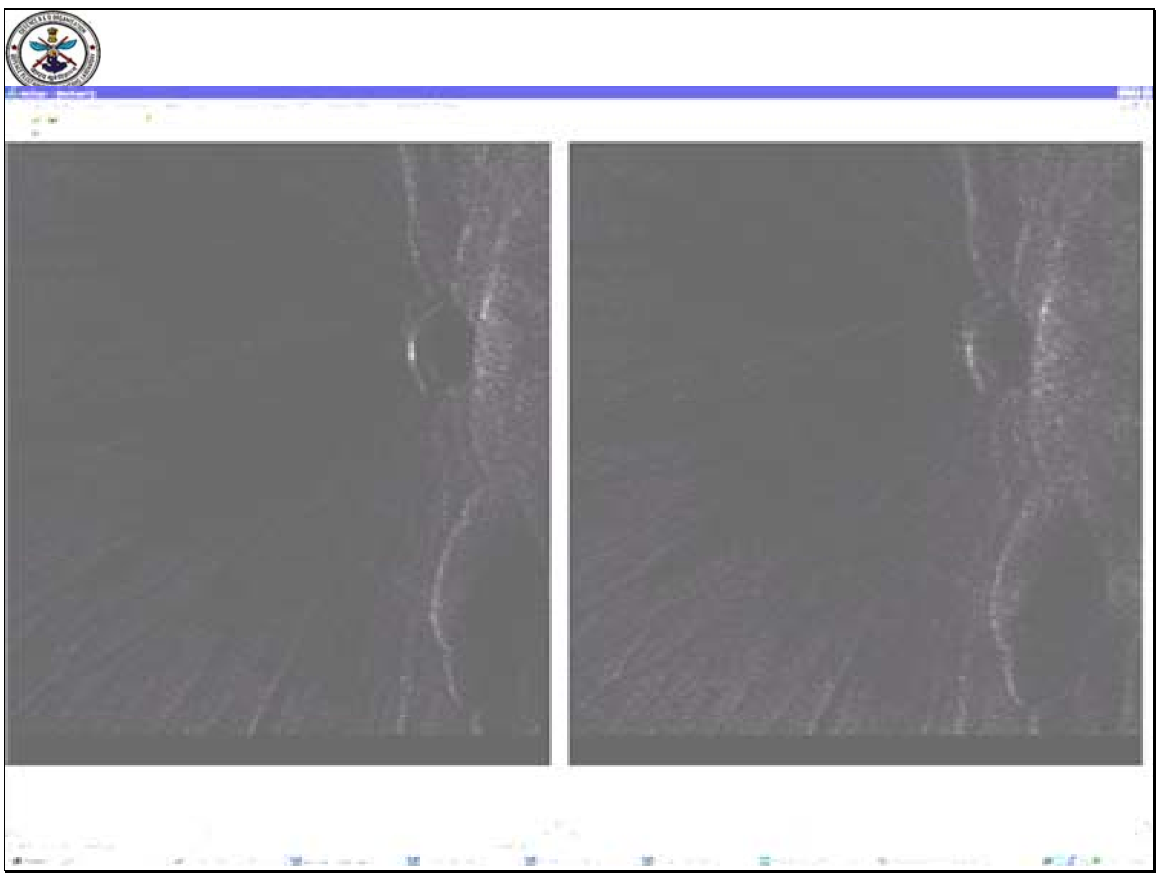
Interferometric SAR viewing Geometry

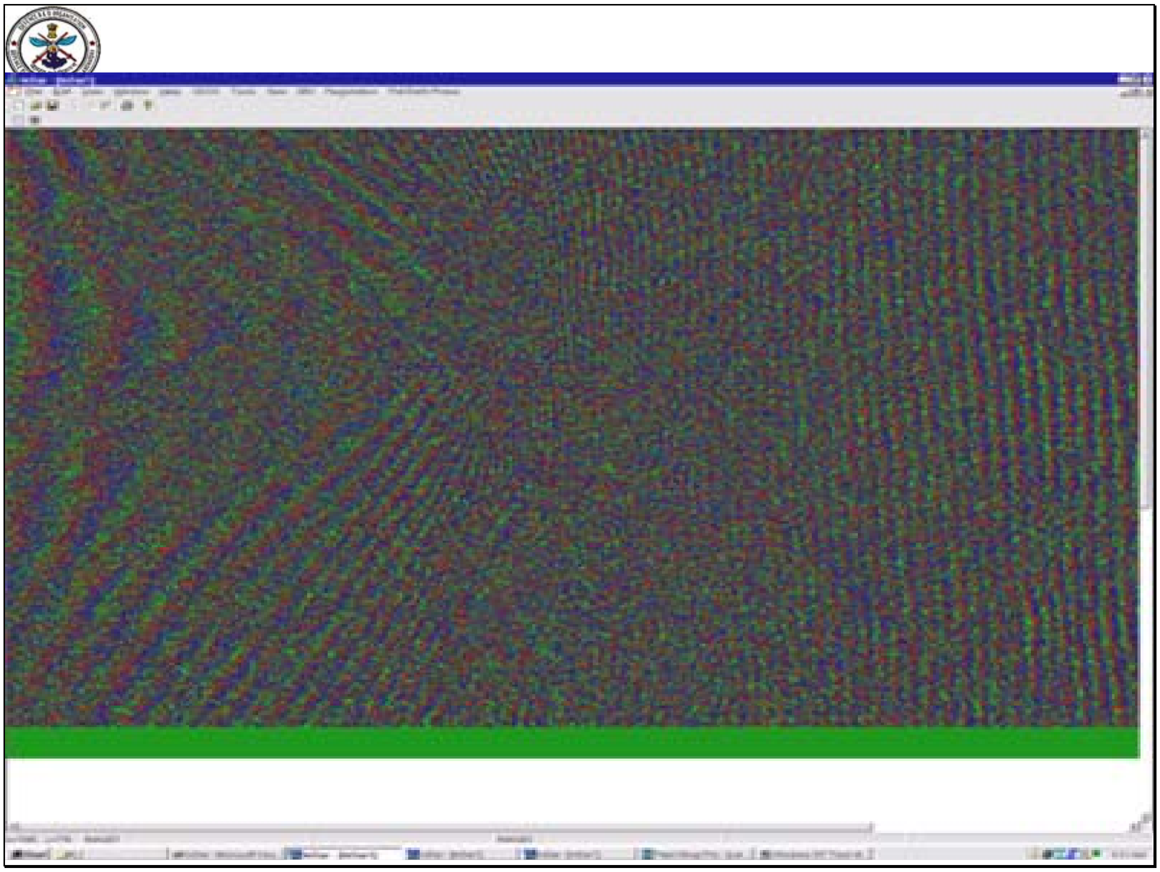
INTERFEROMETRY

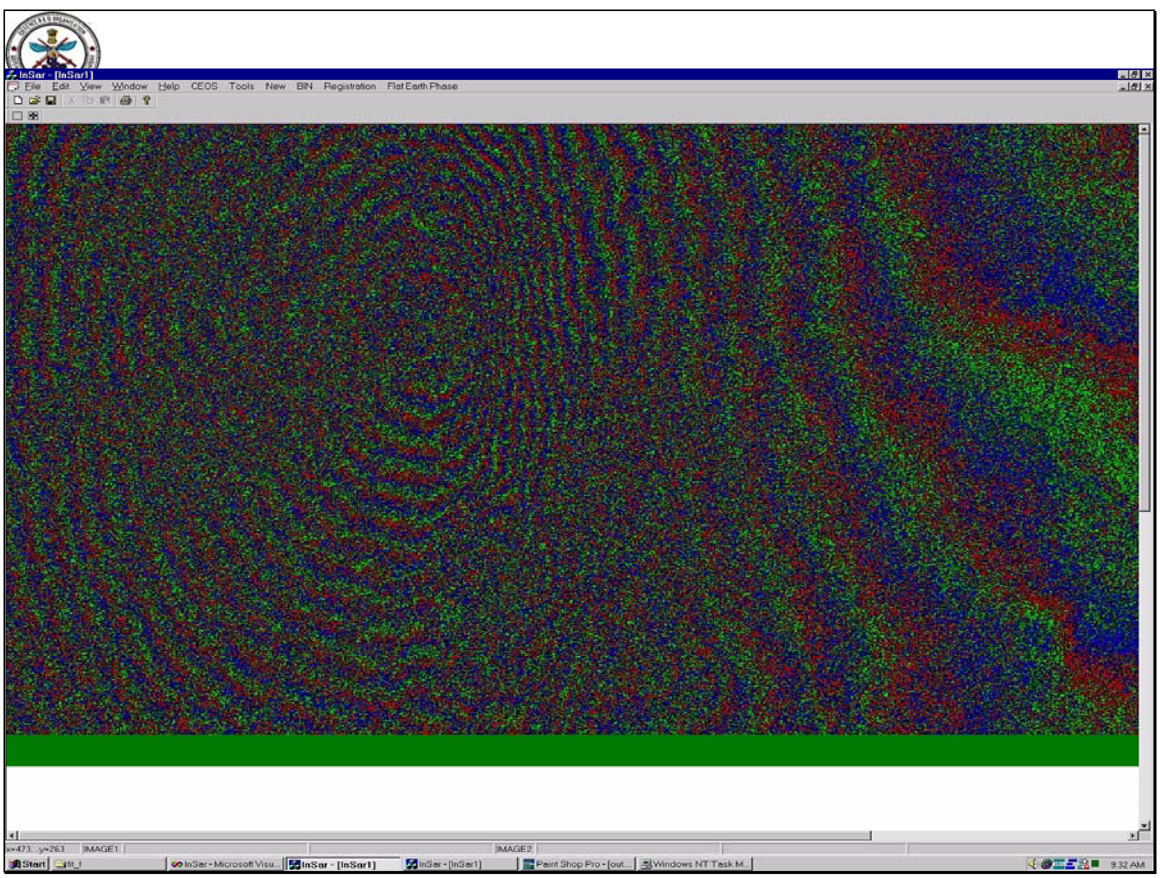


Interferometric synthetic aperture radar (IFSAR) data can be acquired using two antennas on one aircraft or by flying two slightly offset passes of an aircraft with a single antenna. Interferometric SAR can be used to generate very accurate surface profile maps of the terrain.





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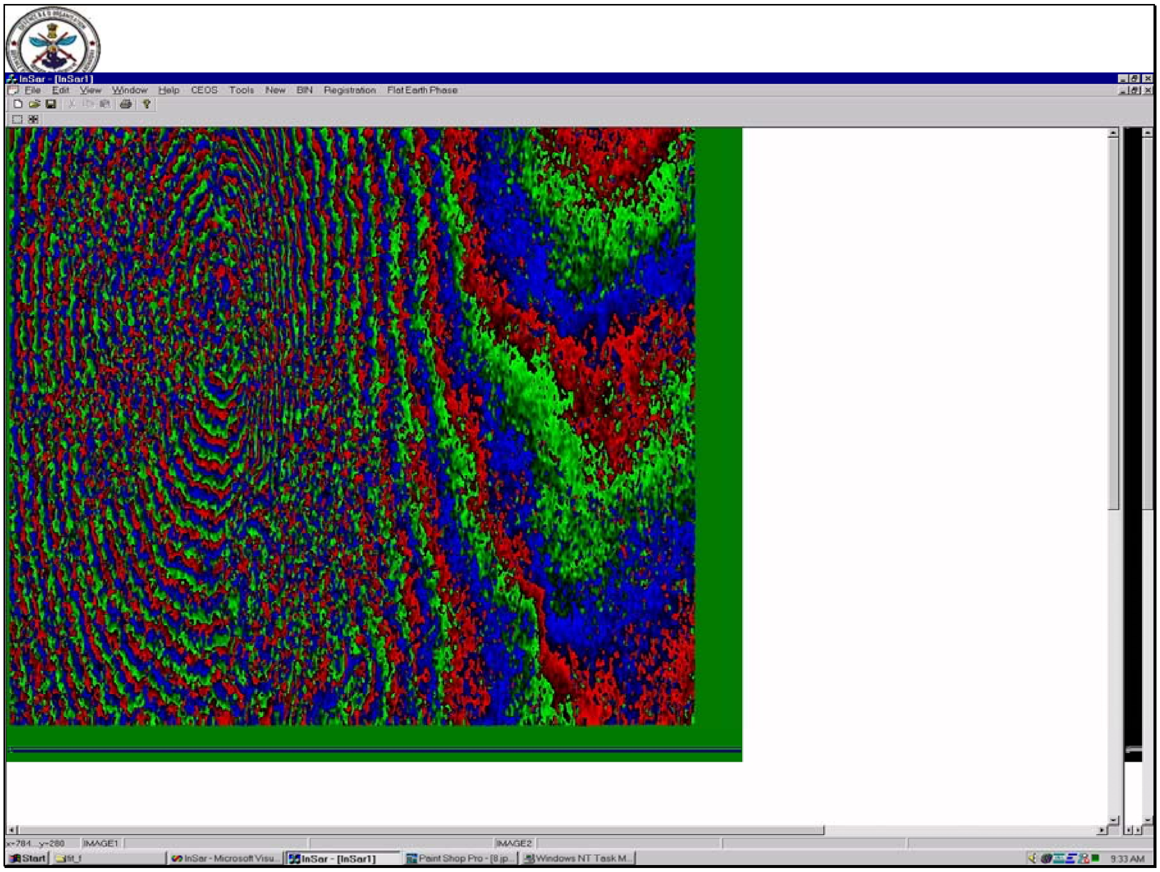
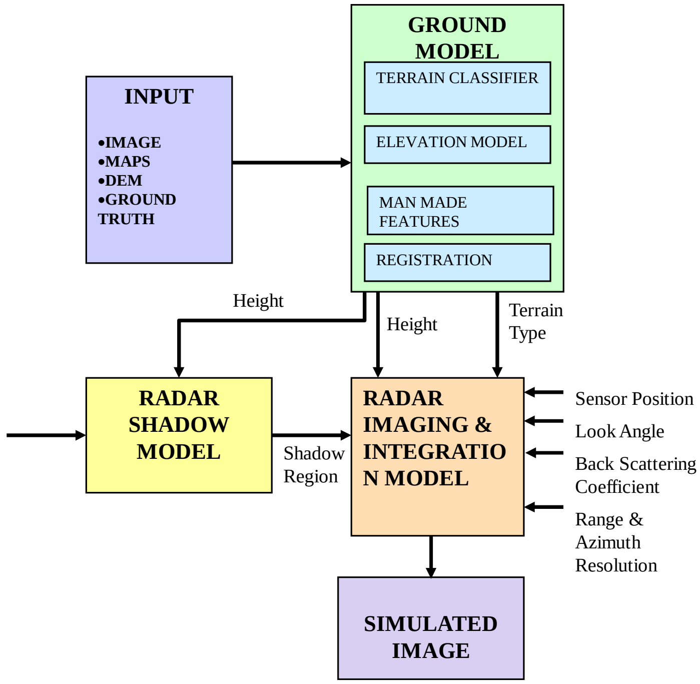
File Edit View Window Help CEOS Tools New BIN Registration Flat Earth Phase
IMAGE1
IMAGE2
Start
InSar - Microsoft Visu...
InSar - [InSar1]
InSar - [InSar1]
Paint Shop Pro - [out...
Windows NT Task M...
9:32 AM


InSar - [InSar1]
File Edit View Window Help CEOS Tools New BIN Registration Flat Earth Phase
IMAGE1
IMAGE2
Start
InSar - [InSar1]
9:33 AM


DEAL

DEAL

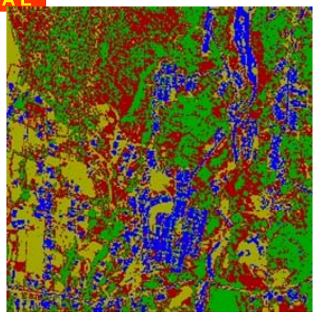
SCHEME FOR RADAR IMAGE SIMULATION



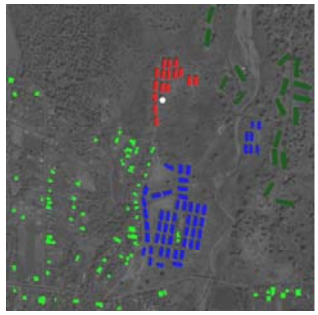
DEAL

Input IKONOS Pan (1 mt.) and Multispectral (4 mt. INSET)

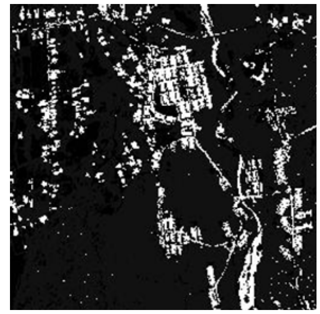
DEAL



Classified Multispectral Image

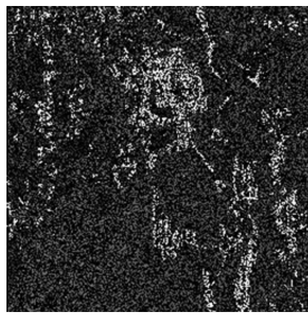


Anthropogenic Feature Map



Reflectivity Map

Backscatter from Anthropogenic features



Simulated X-Band SAR Image

- Sensor Height – 5.2 Km
- Look Angle at Start - 70
- Speckle – Gamma Model
- Imaging – Stripmap Mode
- Aspect Angle - 90
- Spatial Resolution – 4 mt.
- Radiometric Resolution – 8 bit

DEAL

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FUTURE

INTERNATIONAL SPACE STATION

CONSTELLATION

- IMPROVED RESOLUTION
- INCREASED REVISIT
- ALL WEATHER
- DAY & NIGHT

INTEGRATION OF AIRBORNE AND SATELLITE PLATFORMS

- RPVs
- AWACS
- AEROSTATS
- CONSTELLATION OF SATELLITES

MICRO SATELLITES

- CLUSTER OF VERY SMALL SATELLITE (VIRTUAL SATELLITE)
- IMPROVED MANOUVERABILITY
- DISTRIBUTED APERTURE TECHNOLOGY (SAR)

INTERNATIONAL SPACE STATION

SPACE TOURISM

DEAL

THANKS

Speaker Profile

SC Jain did his M.Sc in Physics in 1968, and PhD in 1989. He is in DEAL since 1969. He has worked on various projects; the important ones are Tropo Scatter Communication system, Multispectral scanner, Image processing using Phase Conjugation techniques, Optical Correlator and development of Image Processing Software Packages. He was Indo-US fellow at University of Alabama USA in 1985-86. He was involved in the active mode locking of Lasers.

He has more than 75 publications to his credit out of which more than a dozen are in international conferences and journals. At present he is Group Director of Image Analysis Center at Defense Electronics Applications Laboratory, Dehradun.

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Dehradun
Phone: 0135-2787073, 09411113871

Issues and Solutions for Image Fusion

Dr Subrata Rakshit, Sc F, CAIR, Bangalore

With the advent of high quality (and reasonably economic) digital imaging sensors, there are many applications where one can now talk about providing "image fusion" solutions. In this talk, we will first talk about the various ways in which it is feasible to fuse images. Fusion can mean creating of a composite image from two or more live image (or video) feeds. The object of such a fusion could be to enhance spatial coverage (mosaic), provide sharper picture (better depth of focus) or combine details from multi-sensor inputs. Fusion could also mean fusion of a-priori, static, information with a live feed leading to an annotated imagery (sometimes called augmented reality). For each of these cases, the underlying techniques will be explained and some sample results shown to give an idea of what is possible. The second part of the talk will focus on the issues. From the user perspective, what needs to be done to ensure reliable fusion and, given fusion, how does it relate to usage of imagery. Current understanding allows one to articulate the engineering requirements for building fusion systems. The usage of fusion is, unfortunately, still poorly understood. Nevertheless, an attempt will be made to discuss this issue in the context of avionics and flight safety.

IMAGE FUSION

Dr S. Rakshit

Computer Vision Group
M.K.Nema, A.Jamal, A.G.Faheema, Savitha D.K.,
A.Mishra, B.Sharma, R.Shah, A.Lakshmi, N.K.Sharma

Centre for AI and Robotics (DRDO)

Image Fusion: Example

- Combining different illumination conditions

Image1

Image2

Fused Image

Image fusion: textbook example

- Combining different optical, IR

Optical Images

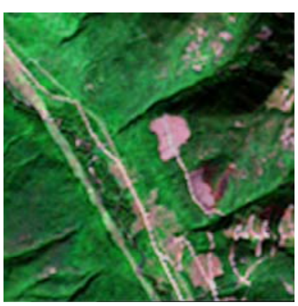
Thermal Images

Fused Images

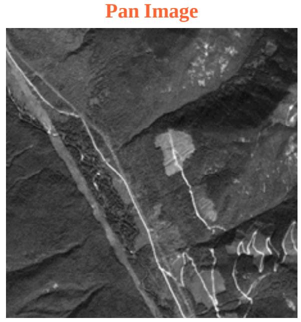
Image fusion: satellite imagery

- Intensity and color (spatial vs spectral details)

Multi-spectral Image



Pan Image



Fused image

MSDF for Imagery: Video Example

- Focused Background

- Focused Foreground

- IR frames

MSDF for Imagery: Fused Videos

- Fusion of above two Optical sequence: focussed background and foreground

- Fused IR-Optical sequences

Image Fusion: 4 basic steps

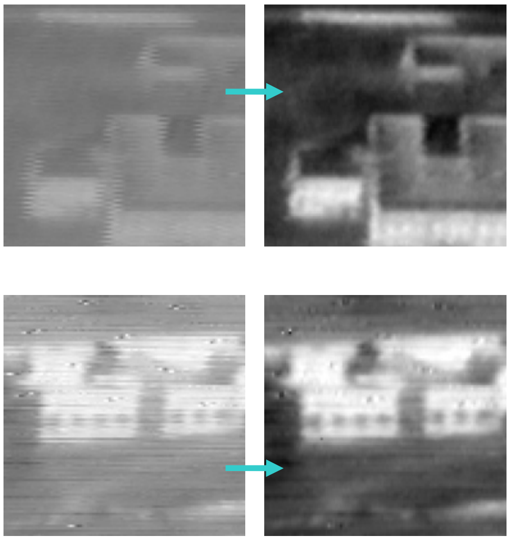
- Data Pre-processing (enhancing images)
- Data Alignment (registering images)
- **Data Fusion (combining images)**
- Presentation (highlighting what is important)

Details of Image Fusion Step 1

- **Data Pre-processing (enhancing images)**
  - Noise removal / reduction
  - Bias, contrast, range, histogram, resolution, size
  - Standard image processing methods.
- Data Alignment (registering images)
- Data Fusion (combining images)
- Presentation (highlighting what is important)

Preprocessing before fusion

We want signal fusion, not noise fusion!



Raw imgs Processed imgs

TASKS

Remove false edges

Equalize contrast, bias

AIMS

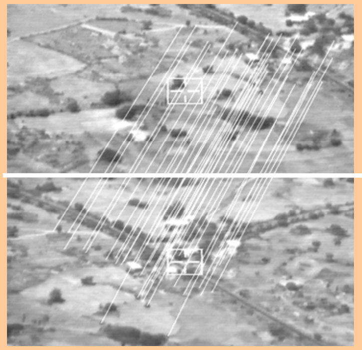
Make matching easier

Make fusion simpler

Details of Image Fusion Step 2

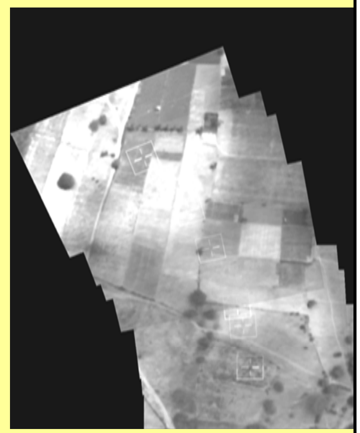
- Data Pre-processing (enhancing images)
- **Data Alignment (registering images)**
  - Rendering one image to have the coord system and perspective of another image
  - The MOST difficult part for automation
  - Correlation, key point matches, projective geometry
- Data Fusion (combining images)
- Presentation (highlighting what is important)

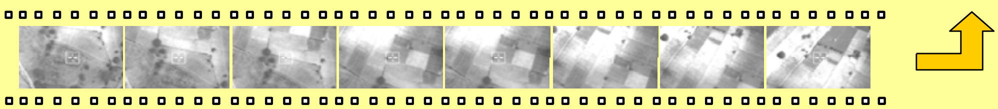
Registration and Mosaics



Auomatic registration
*** Key Point detection**
*** Vectors & Metrics**
*** Robust Homography**

Mosaic from video





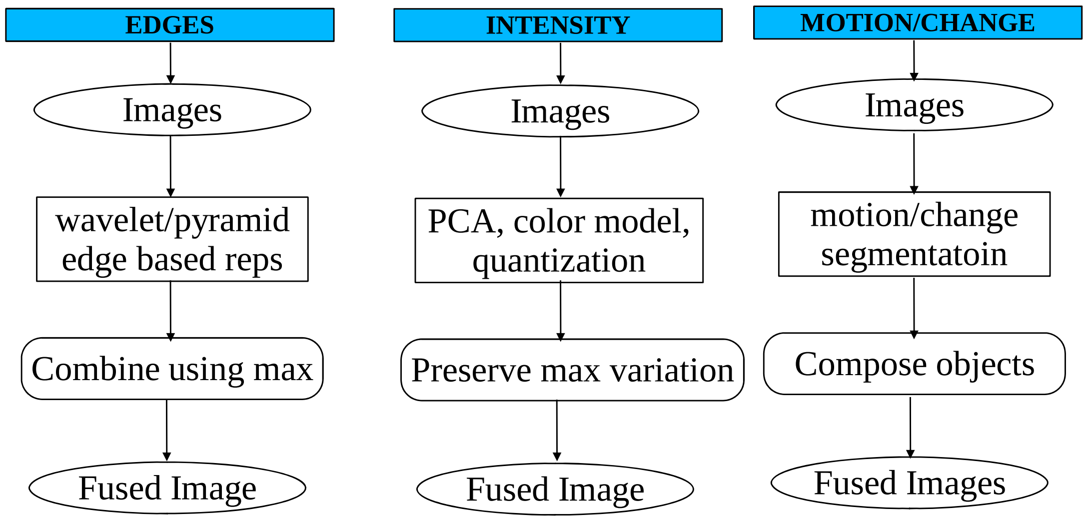
Details of Image Fusion Step 3

- Data Pre-processing (enhancing images)
- Data Alignment (registering images)

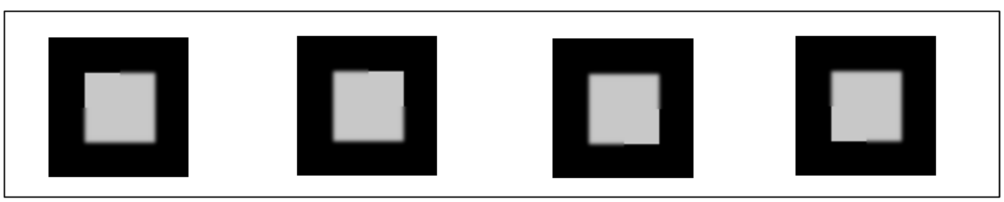
- **Data Fusion (combining images)**
  - Choosing a representation (deciding what is important)
  - Applying a fusion rule in the transform domain
  - Reconstructing the composite image

- Presentation (highlighting what is important)

Edge, Intensity, Motion, Change:
Which do you define as 'signal'

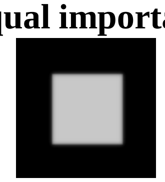


Edge Fusion vs Addition
Underlying belief system matters

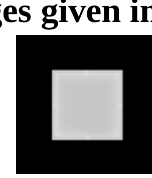


4 inputs

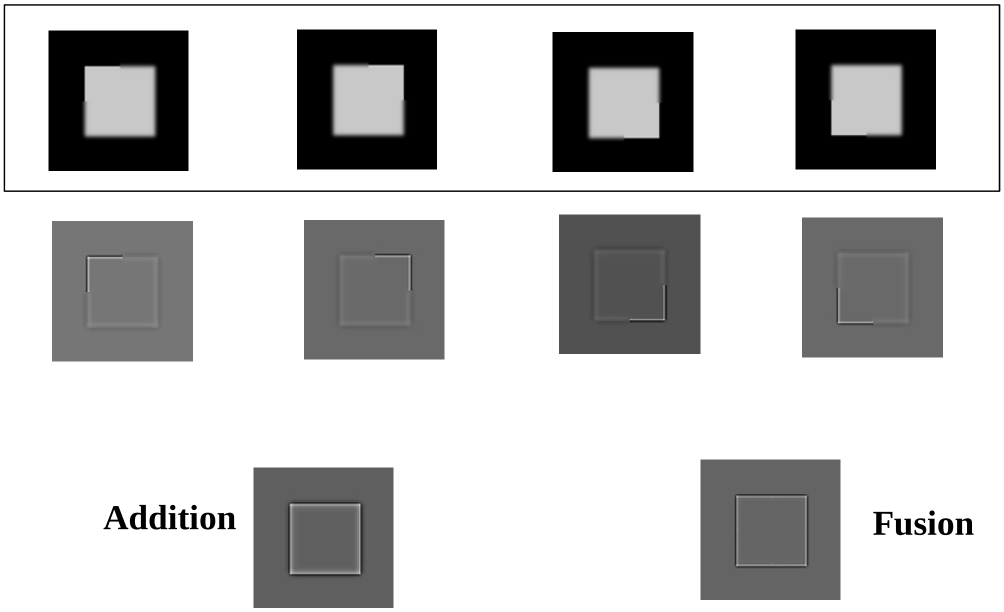
Addition:
Equal importance



Fusion:
Sharp edges given importance



Edge Fusion vs Addition



Intensity Fusion vs Averaging

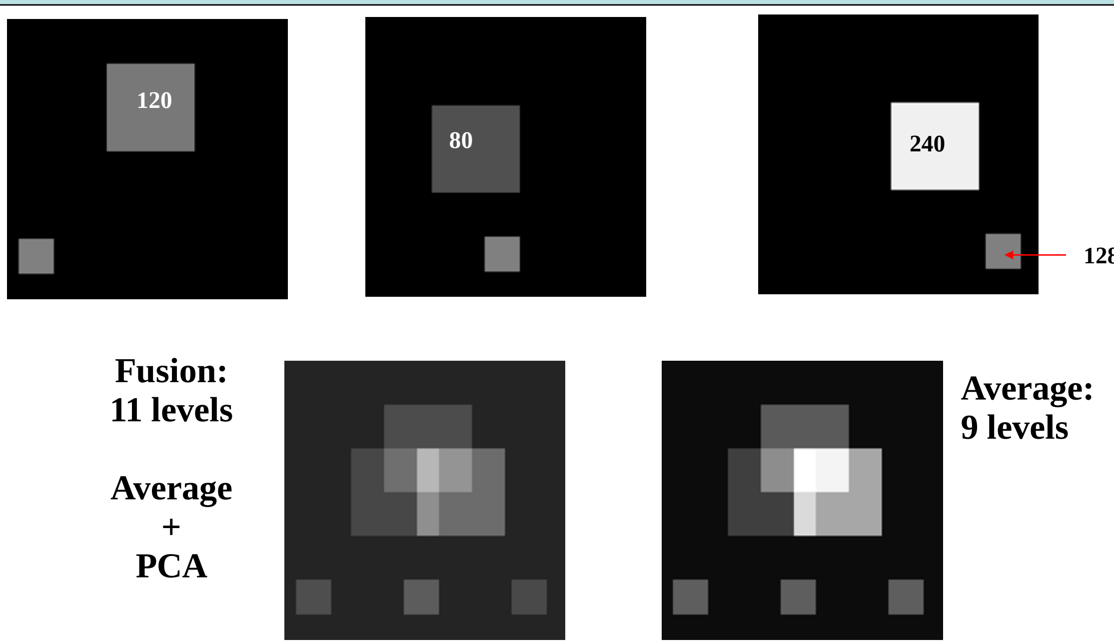


Image Fusion: optical and IR
(Daylight details + Night targets)

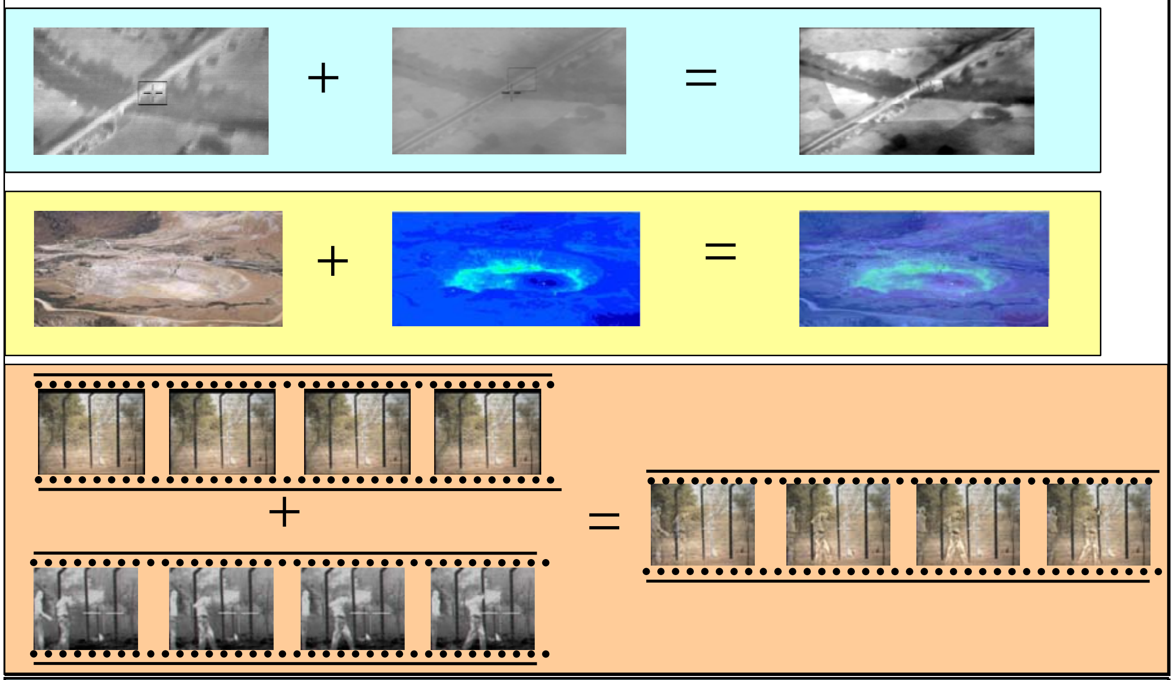
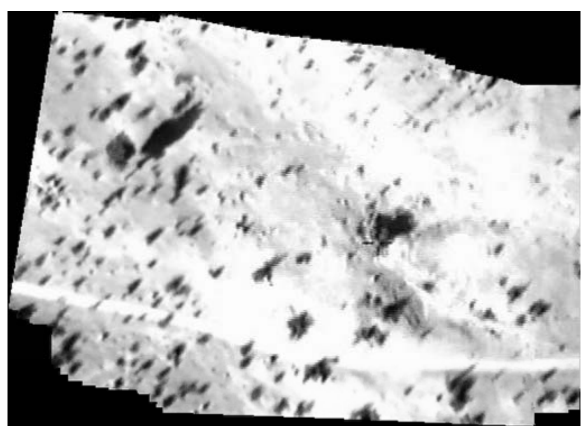


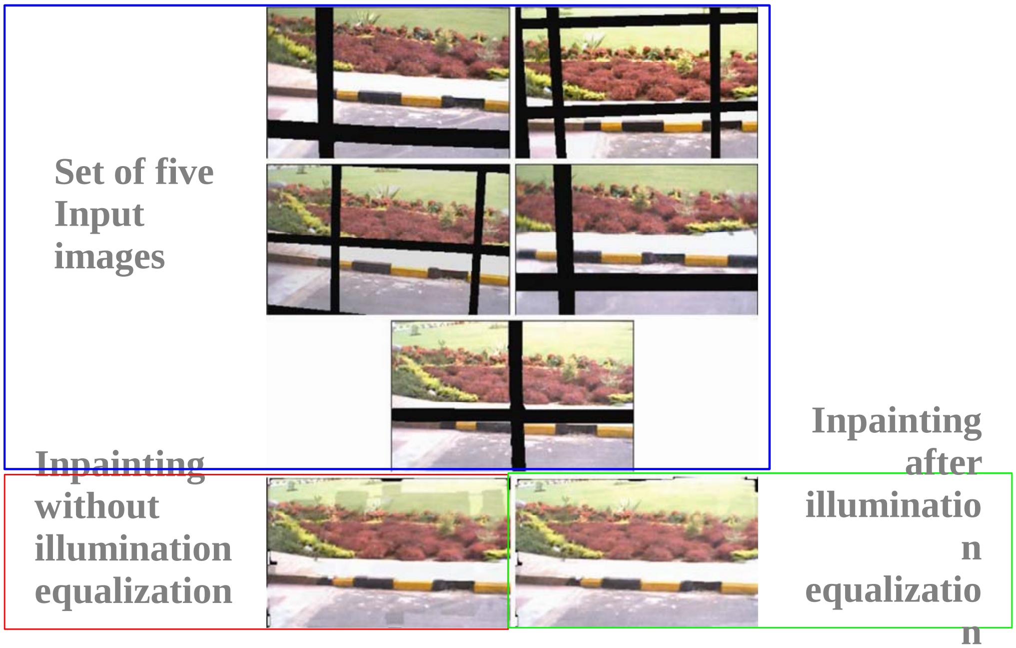
Image Fusion: Mosaic + Foreground Composition

Original clip



After processing

Multi-view Fusion:
In-Painting Occlusions



MSDF for Imagery: Step 4

- Data Pre-processing (enhancing images)
- Data Alignment (registering images)
- Data Fusion (combining images)

- **Presentation (highlighting what is important)**
  - **Fusion is NOT addition or a linear process**
  - **What we throw away decides what stands out**
  - **MSDF is always specific for an application**

MSDF for Imagery
Improving presentation

- **Fused IR-Optical sequences**

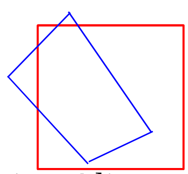
- **Fused IR-Optical (after clutter removal by object segmentation in IR)**

UAV and Satellite Imgs: Preprocessing, Registration, Fusion and Geo-registration

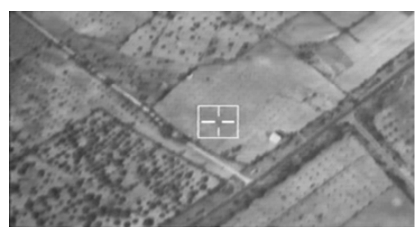
A B

C D

Satl (Ikonos)



View Alignment of Satellite and UAV



UAV (Nishant, ADE)

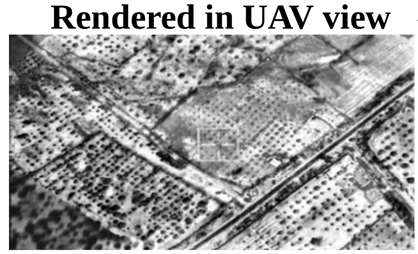
Rendered in satl view

A B

C D

Fusion Results

a **Rendered in UAV view** b



c d

What is the Image Fusion problem we need to solve for ESV

- **Reasons for fusion**:
  - Multiple cameras for wider coverage
  - Multiple sensors for all weather coverage
  - Fusion of real and reference imagery / information
    - Collation of information
    - Update of parameter estimates
- **Engineering aspects**
  - Data fusion versus display fusion
  - Auto-registration versus (fixed) ***calibrated cameras***
  - Sensor costs versus software complexity
  - Modification of Environment for sensor suite

Multi-Sensor Displays

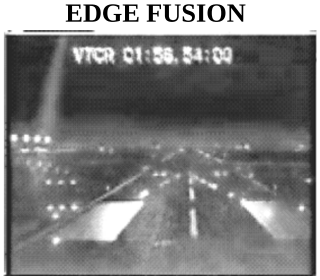
DISPLAY FUSION

LWIR

OPTICAL

SWIR

EDGE FUSION



INTENSITY FUSION

VARIATION FUSION

Multi-Sensor Displays
Importance of accurate registration

DISPLAY FUSION

LWIR

OPTICAL

SWIR

EDGE FUSION

INTENSITY FUSION

VARIATION FUSION

Display Fusion or Data Fusion?

Optical Image

White is color

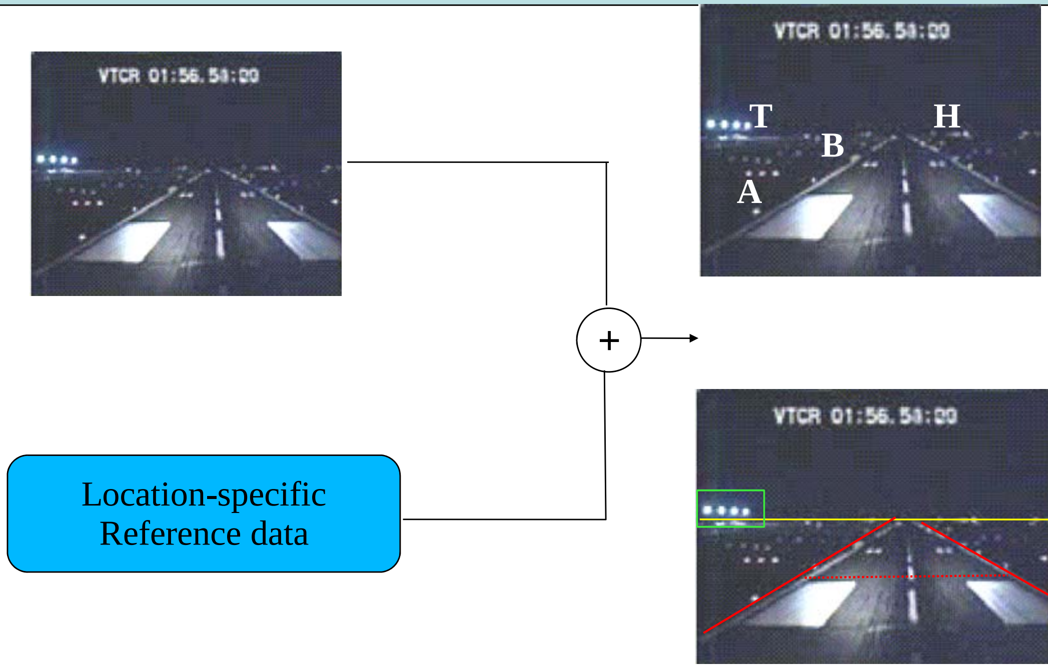
Thermal Image

White is hotter

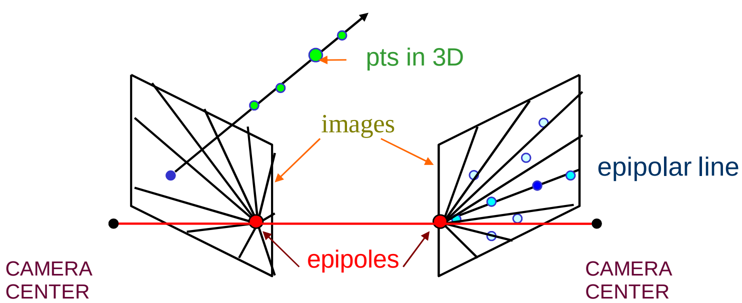
Fused Images

Is the man wearing a white coat?
Is the building hot?

Annotated Imagery



THE 3D WORLD AND MULTIPLE CAMERAS: EPIPOLAR GEOMETRY



F matrix [3x3, rank-2] captures the relation

USING EPIPOLAR GEOMETRY FOR MATCHING

BASIC PROBLEM

- Epipolar constraint can **boost** point matching
- Epipolar constraint **needs** point matches

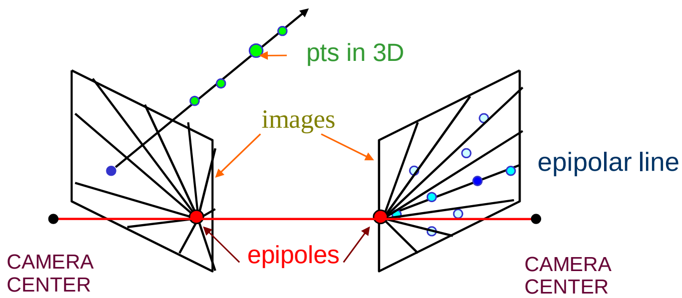
Approach

- Boot strap with initial matches
- Ensure numerical stability by handling outliers
- Re-compute (unique) F

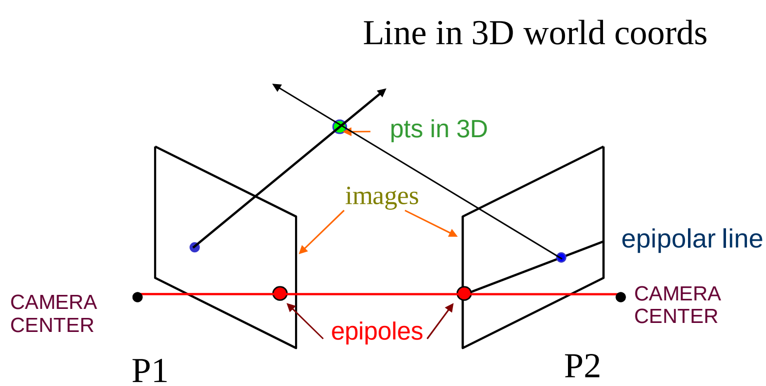
PAYOFFS

- 2D to 1D search
- F gives relation between cameras needed for 3D

If only F was given up front: **Calibrated Cameras**



THE 3D WORLD AND CALIBRATED CAMERAS:



P matrix [3x4] maps image point to line in 3D world coords

F matrix can be computed from P1 and P2

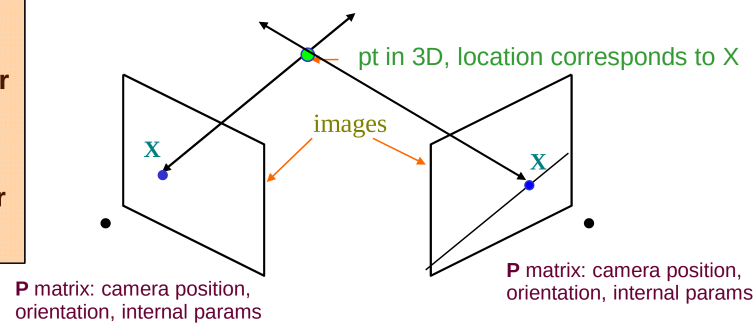
USING MULTIVIEW GEOMETRY FOR IMAGE ANNOTATION

PROBLEM DEFINITION
Annotate live imagery with information in database

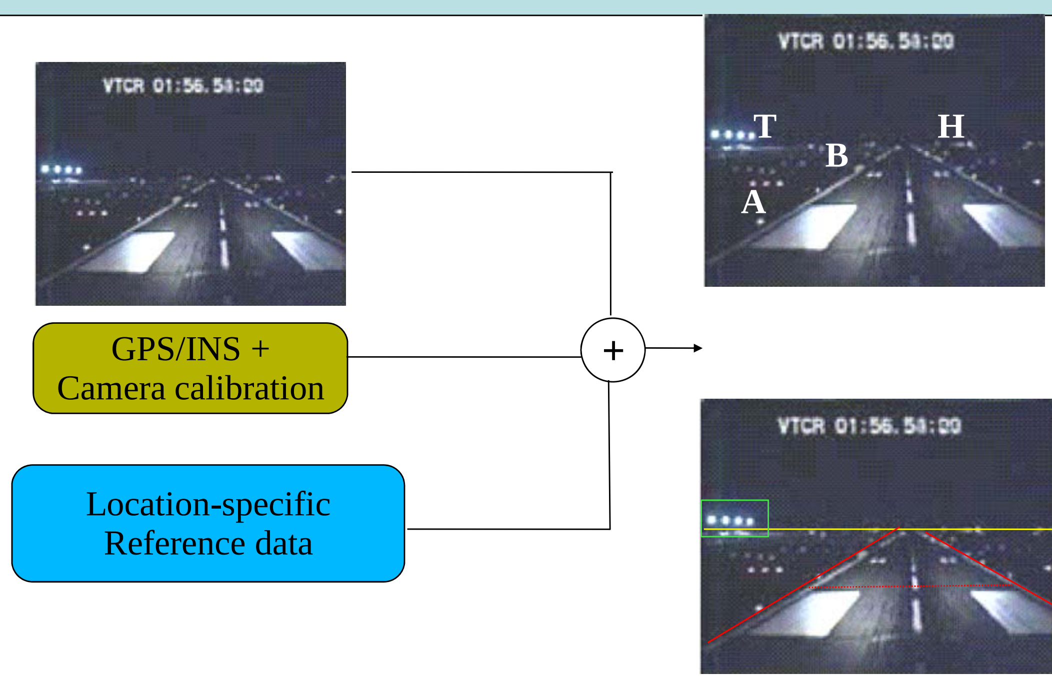
Approach

- Get F from P. Boost matches
- Triangulate matches to map image features to 3D coord syst.
- Pick up info from database and annotate images

- **Needs good position & orientation estimates**
- **Needs large baseline**
- **Useful if image is not clear, or area is unfamiliar to human**
- **Bypasses the problem of object recognition in poor images**



Annotated Imagery
(Assuming pilot vetos total simulation)



Annotated Imagery
(Assuming pilot allows overlays)

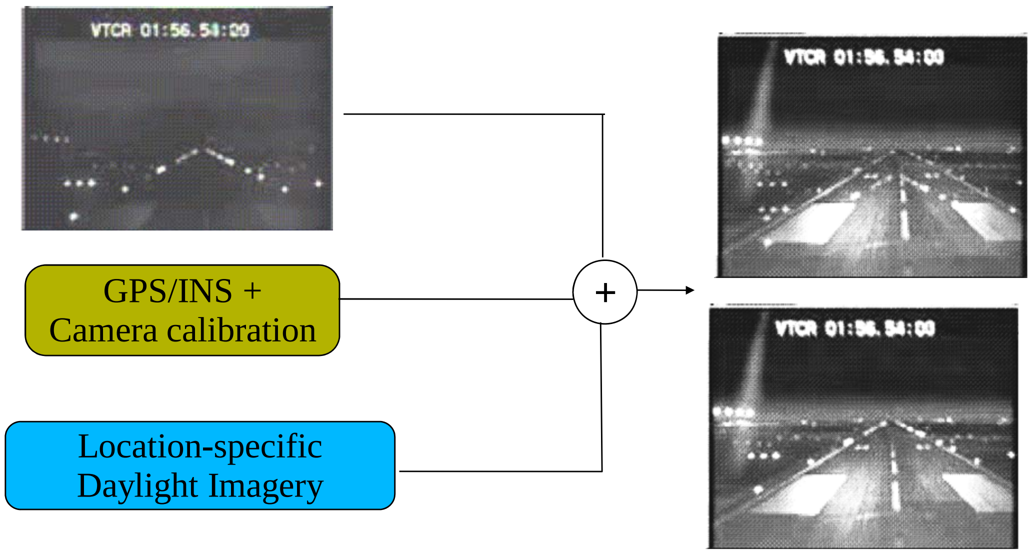


Image Fusion for ESV

- 1-2-3 Steps:
  - Determine the usage scenarios: what does pilot need?
  - Determine the sensor types: try to solve problems as simply as possible by picking good sensors
  - Use image fusion if some gap needs to be filled
- Engineering aspects
  - Fix whatever can be fixed: sensor choice, mounting
  - Perform sensitivity, error analysis before promising
  - Cross check with user before freezing system goals
  - Keep an open mind regarding problem definition

Speaker Profile

Dr Subrata Rakshit did his B.Tech in Engineering Physics from IIT-Bombay in 1984-88. He did his M.S and PhD from Caltech, USA in '89 and '94 respectively. After a brief post doc at Washington Univ of St Louis, he returned to India and joined CAIR(DRDO) in Dec 1994. Since 2000, he has been heading the Computer Vision group of CAIR. He has worked in the areas of SAR scene correlation, Content Based Image Retrieval, Progressive Image Transmission and Multi-Sensor Data Fusion for Imagery.

He has also worked on neural networks and information security. He received the DRDO Technology award in 1996, the CAIR Laboratory Scientist of the Year award in 2005 and the CAIR Technology Group Award in 2006.

Infrared Sensors Technology

Dr. SS Negi, Sc 'G', IRDE, Dehradun

By virtue of being true passive in nature, IR systems are finding applications for all ground, ship borne and airborne operations. These systems provide enhanced synthetic vision and are becoming a necessity in all strategic defense missions and exploit 3-5µm (MWIR) and 8-12µm (LWIR) spectral bands of Electromagnetic Spectrum. Selection of each band will depend upon the application. MWIR band is preferred for hot & humid environment and long range application including airborne platforms, whereas LWIR band is preferred for ground to ground application up to 6kms in dusty environment.

With the advancement of subsystem technologies, i.e. optics, detector, signal processing, IR systems have graduated from 1st generation to 3rd generation systems. The different generation systems utilize the following types of detectors.

1st Generation

- LWIR 8 to 12µm.
- Linear array of single detector elements, e.g. 60,120 or 180 x 1or 256 x1.
- Cooled to 80 K
- Two dimensional electromechanically scanned.

In case of 1st generation IR systems, the output from each detector is taken out of the dewar and signal processing is done outside the focal plane. These systems have resolution varying from 250µrad to 60µrad providing a typical FOV 4° x 2° and sensitivity in the range of 180mK. 1st generation systems were phased out by 2000.

2nd Generation

- HgCdTe, LWIR 8 to 12µm.
- Use several horizontal or vertical strips (serial or parallel) of cooled detectors
- Larger linear array of multiple elements e.g. 96/240/288/480/960 x 4, 768 x 6
- Cooled to 80 K
- Scanned in one direction
- Partial signal processing is done on the FPA itself which includes Time Delay Integration (TDI) to improve system sensitivity, multiplexing to simplify Dewar design and low heat load and preamplification.
- TDI improves the S/N by square root of the number of detector elements in scanning direction resulting in providing longer ranges compared to 1st generation systems.

2nd generation systems were developed and made commercially available from 1990 onward. These systems provide 40% better discrimination than 1st generation systems, but they pose problems of complex signal processing and fixed pattern noise compensation in real time.

3rd Generation

- MWIR (3-5 µm) and LWIR (8 - 12 µm).
- Densely packed staring array of detectors, e.g. 320x256, 640 x 512, 1K x 1K.
- Cooled or uncooled.
- They do not require scanning as full matrix covers the entire FOV.
- On focal plane signal processing includes signal amplification, multiplexing and even the digitization (ADC) which results in less number of processing elements requirement in external signal processor.
- Proximity electronics, which is part of the IDDCA, includes Non Uniformity Correction, Bad Pixel Replacement and Dynamic Range Compression.

3rd generation IR systems were developed and productionized based on 320 x 256 staring formats operating in the 3-5µm region.

These systems were commercially available from 2000. More number of elements in the focal plane increases the (a) FOV, (b) sensitivity allowing target identification at longer ranges and/or under adverse conditions which the users were always demanding. Requirements of more and more FOV coverage and better target discrimination capability has forced the detector manufacturer to go for higher and higher format arrays with smaller pixel sizes resulting in the development of 480 x 384, 640 x 512 and 1K x 1K detectors with pixel size reducing to 15µm.

3rd Generation+ Systems (Likely to come in near future)

- SWIR, MWIR, LWIR
- Large format staring arrays of detectors > 1 K x 1K.
- HgCdTe, InSb, QWIP
- Dual color/ dual band (application dependent – two sub bands within MWIR for dual color and MWIR & LWIR for dual band)
- On chip processing, no external processing
- Cooled or uncooled
- Element size: 15µm

For airborne platforms, there is a requirement of multisensory system comprising of FLIR & CCD &/or SWIR systems.

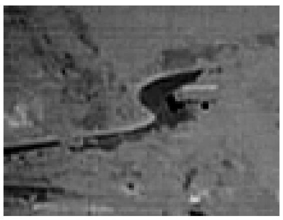
The total system is required to be stabilized to give images of the targets free from aircraft vibrations.

New Technologies:

- SWIR imaging is a new area which will be complimentary to IR system and will provide higher resolution. SWIR systems may be part of airborne package for future systems.
- As increasing no. of sensors such as CCD, IR and SWIR will be utilized for synthetic imaging there will be need for image and pixel fusion.

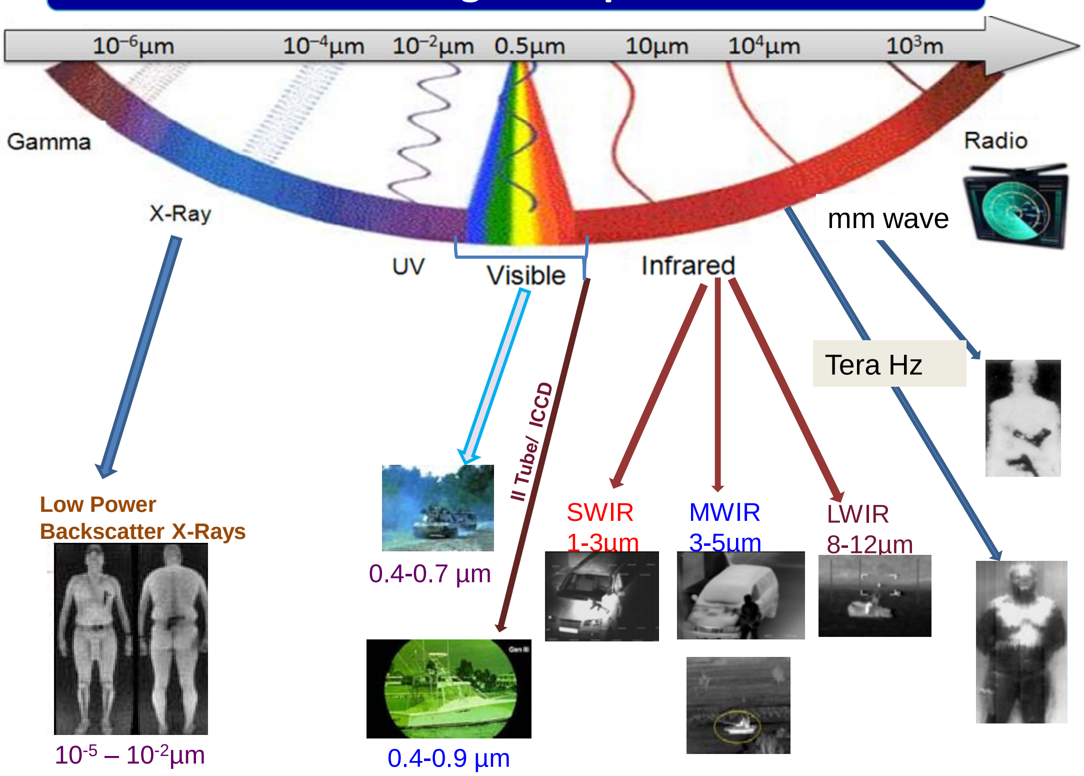
Presentation 26th Apr 08

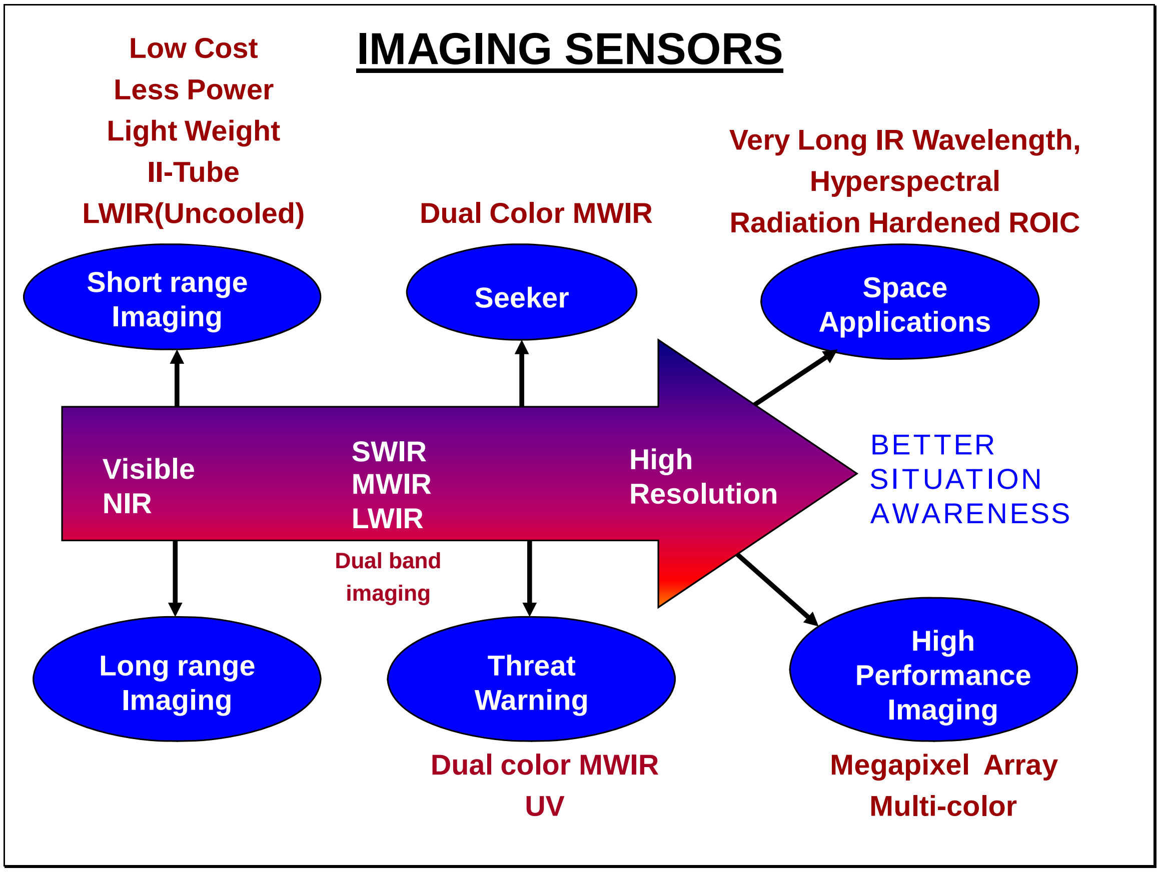
INFRARED SENSOR TECHNOLOGY

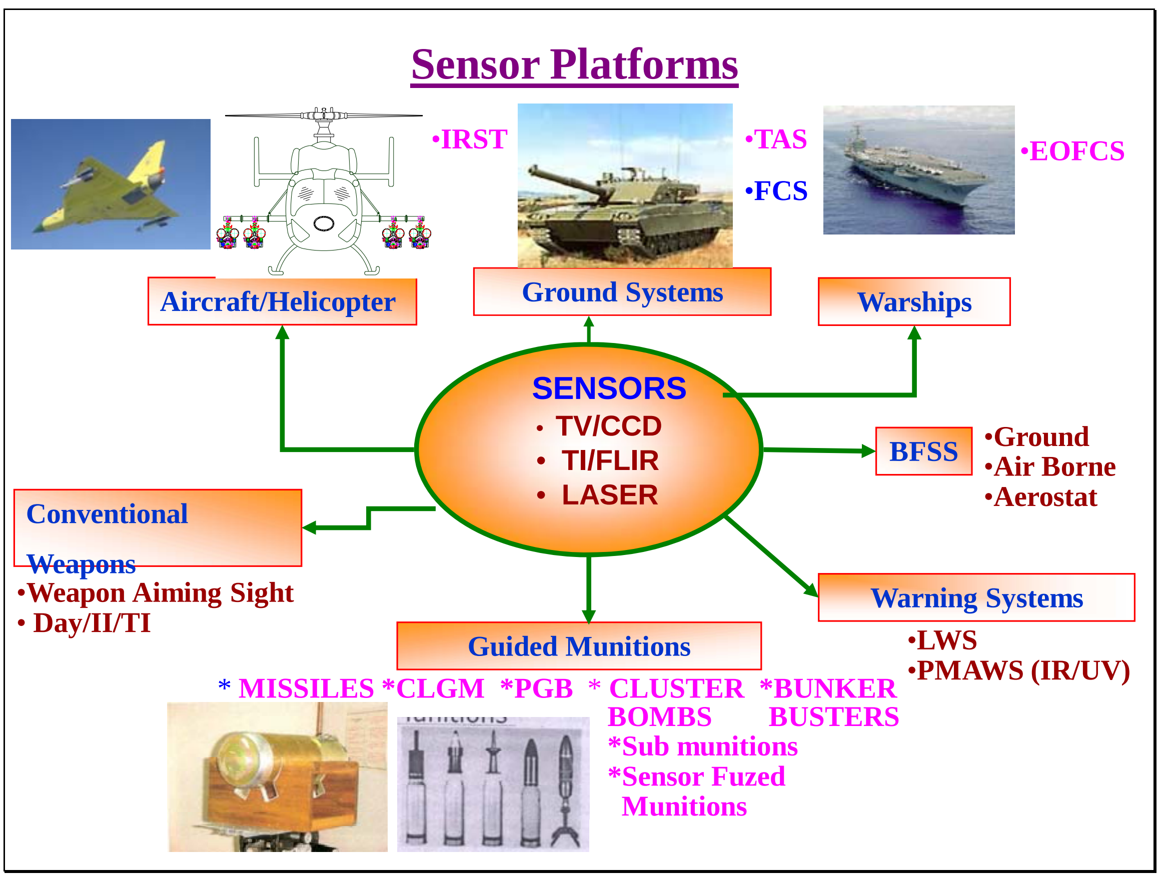


Dr S S Negi
Scientist G
IRDE, Dehradun

Electromagnetic Spectrum



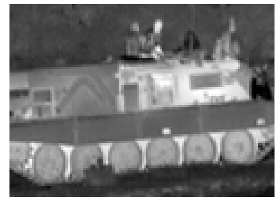

IMAGING SENSORS
Low Cost
Less Power
Light Weight
II-Tube
LWIR(Uncooled)
Dual Color MWIR
Very Long IR Wavelength,
Hyperspectral
Radiation Hardened ROIC
Short range Imaging
Seeker
Space Applications
Visible
NIR
SWIR
MWIR
LWIR
High Resolution
BETTER SITUATION AWARENESS
Dual band imaging
Long range Imaging
Threat Warning
High Performance Imaging
Dual color MWIR
UV
Megapixel Array
Multi-color


Sensor Platforms
•IRST
•TAS
•FCS
•EOFCS
Aircraft/Helicopter
Ground Systems
Warships
SENSORS
• TV/CCD
• TI/FLIR
• LASER
BFSS
•Ground
•Air Borne
•Aerostat
Conventional Weapons
•Weapon Aiming Sight
• Day/II/TI
Warning Systems
•LWS
•PMAWS (IR/UV)
Guided Munitions
* MISSILES *CLGM *PGB * CLUSTER BOMBS *BUNKER BUSTERS
*Sub munitions
*Sensor Fuzed Munitions

Night Vision Sensors

II, ICCD

Thermal Imaging Systems
Ist,IInd IIIrd Generation
(Cooled & Un -cooled)

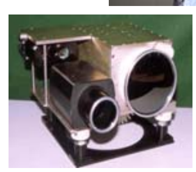


❖Surveillance & Reconnaissance
❖Acquisition & Engagement at short ranges
- ❖ Night Patrolling
- ❖ Vehicle driving
- ❖ Map reading

❖ Surveillance & Reconnaissance
❖ Target Acquisition & Engagement
- ❖ Missile Guidance
- ❖ Missile Warning

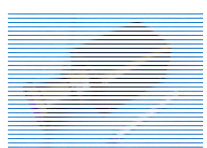
CURRENT SYSTEMS

- ❑ 3rd Gen Image Intensifier NV Goggles (40º FOV)
- ❑ 2nd Gen Thermal Imager (LWIR)
  (LFPA MCT / staring QWIP LWIR)
  - 288 x4
  - 480 x 4



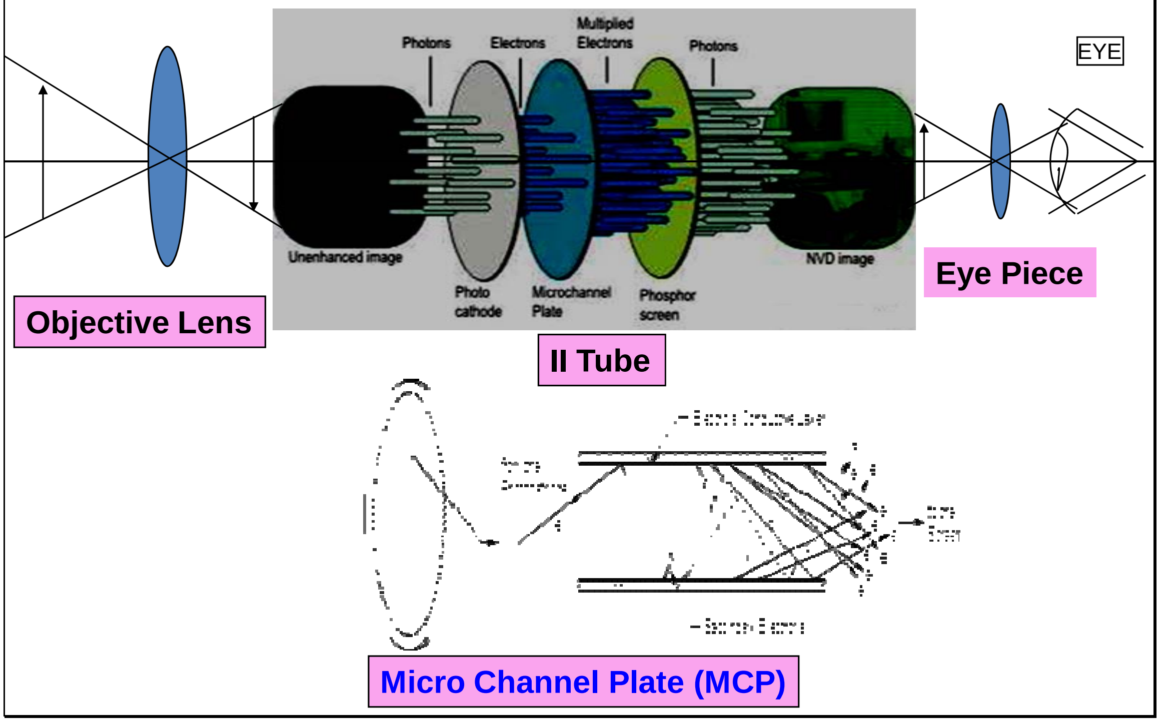
- ❑ 3rd Gen Thermal Imager (MWIR) (Staring InSb FPA)
  - 320 X 256
  - 640 X 512

- ❑ 3rd Gen Uncooled Thermal Imager (LWIR)
  - 160 X 128
  - 320 X 256



- ❑ SWIR – In prototype stage

Image Intensifier Tube based NVD



Evolution of II Tubes

	Supergen	XD-4/XR-5
Resolution (lp/mm) min	45	64/72
PS(μA/lm)	500	700/800
SNR	18	25/27

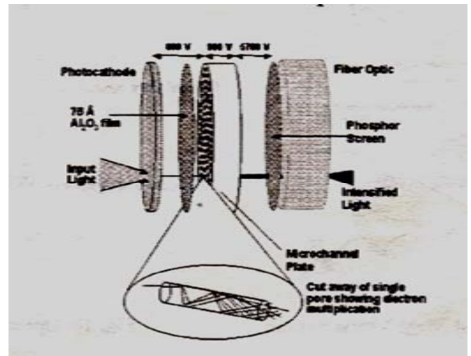
Hyper GEN (XD-4)

Super GEN

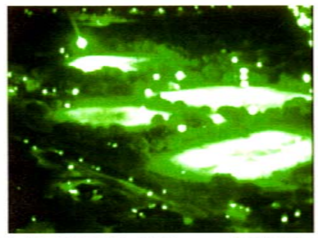
GEN 0	GEN I	GEN II	GEN III	GEN III+
•Photodiode •S-1, Ag-O-Cs •PS: 50μA/lm •Res: 80-100 lp/mm	•Electrostatic Focus •S-20, Multialkali •PS: 50-100 μA/lm •Res: 22-36 lp/mm	•MCP,Proximity Focus •S-25, Multialkali •SNR: 14 •PS: 100-400 μA/lm •Res: 22-36 lp/mm	•MCP,Proximity Focus •GaAs • SNR: 22 •PS: 600-1800 μA/lm •Res: 36-64 lp/mm	•Unfilmed MCP •GaAs • SNR: 27 •PS: 2200 μA/lm •Res: 72+ lp/mm
1950's	1960's	1970's	1980-90's	2000+

Advanced II Technologies

1. Unfilmed MCP II Technology
2. Auto-gated Power Supply Technology
3. Halo Free II Technology
4. Reduced II Format (16mm II Technology)

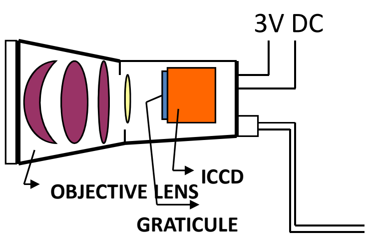


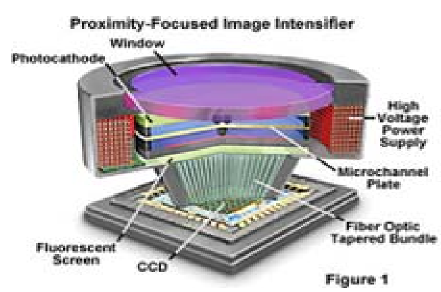

Standard Fielded Gen III


Unfilmed MCP Gen III (Autogated, Halo Free)

Gen III **Unfilmed tube**

Intensified CCD Sight





Advantages

- Analog/ Digital video o/p
- Remote display possible
- Viewing comfort
- Image processing & fusion with other sensors

Night Vision Sensors [II based]

IRDE has developed a family of passive night vision devices for various applications.

Gap Measuring Device Mark -II
FOV: 6°
Magnification: 6X
LRF Range: 999   1 m

PASSIVE NIGHT VISION GOGGLE
Magnification : 1X
Field of view   : 40
Recognition Range : 225 m for B vehicle

Passive Night Vision Binocular (Mk-I)
Magnification : 4X
Field of view   : 10
Weight   : 2.3 kg
Aperture   : 78 mm

Passive Night Sight For 5.56 mm Rifle
Magnification : 4X
Field of view   : 10
Weight   : 1 kg
Aperture   : 60 mm

Recent Developments : NVDs

Mag.   : 1x & 4X
FOV   : 40^0 & 10^0
II Tube: 18 mm XD-4
Range : 250 m, 600m

PNV Binocular with replaceable OG

Mag.   : 5.5X
FOV   : 8^0
II Tube: 18mm XD-4
Range : 700 m

PNS for 84mm RL

Mag.   : 2.5x
FOV   : 10^0
II Tube : 18 mm XD-4
Range   : 200m

PNS for Modern-sub machine Carbine

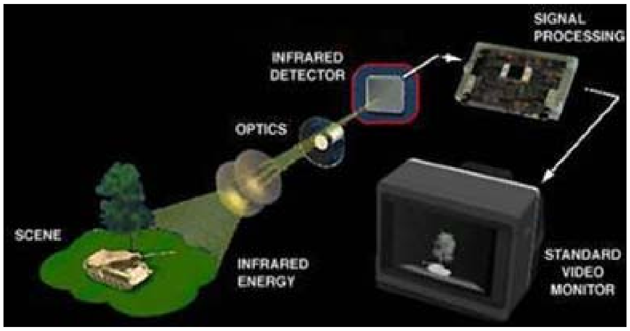
Focal Length: 8mm
FOV   : 80^0 x 60^0
II SuperGen :18mm
Range   : 200m

ICCD Camera for UGV

II Super Gen   : 18 mm.
Gating Speed : 100ns
Range   : 1 Km

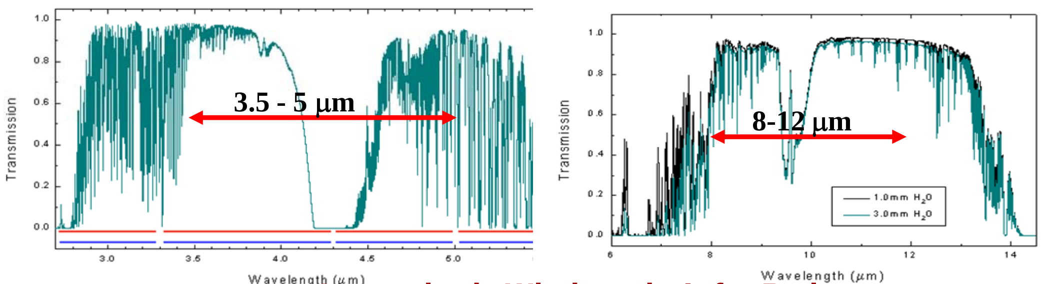
Range Gated ICCD Camera

Infrared Imaging



Features:-

- Operates in total darkness : truly passive
- Less affected by smoke, dust or light rain
- Penetrates light camouflage
- Cannot be blinded by search light & flares
- Reveals the thermal details of the scene
- Detects thermal foot prints
- Longer detection range possible

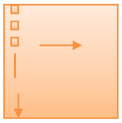


Atmospheric Windows in Infra Red

Comparison between MWIR & LWIR

Parameter	3-5µm (MWIR)	8-12µm (LWIR)
Dusty environment	--------	Better
Cloudy environment	--------	Better
High Atmospheric Temp	Better	--------
Sun glints	More	Less
Humid environment	Better	--------
Optics	Cheaper	Costly
Detector	FPAs	LFPAs, FPAs
Applications		
Short range (*All climates)*	Both can be used	
Medium range (T*emperate)*	Both can be used	
Long range (*Hot & Humid)*	Preferable	--------
Very long range (*All climate)*	Preferable	--------
Better field Surveillance (*Direct Sunlight reflection, Smoke, fire)*	--------	Preferable
Signature Identification (*With High confidence level)*	--------	Preferable

IR DETECTOR GENERATIONS

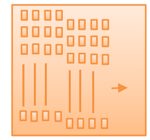


First Generation

Window: LWIR
Material: MCT
Format: Linear array of single detector elements (60 : 1, 180 : 1)
Scanning: 2D electromechanical
Element size: 50µm

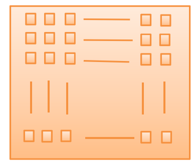
Second Generation

Window: LWIR
Material: MCT, QWIP
Format: Larger linear arrays (288 x 4, 768 x 6)
Scanning: 1D scan
Element size: 30µm



Generation 2 1/2

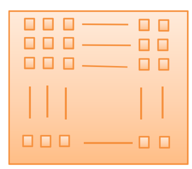
Window: MWIR
Material: MCT, InSb
Format: Staring arrays (320 x 256)
Element size: 25µm

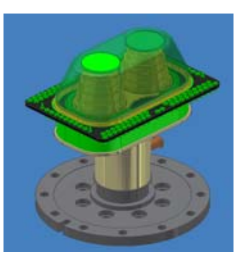


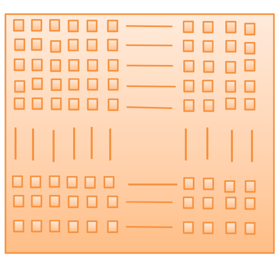
IR DETECTOR GENERATIONS

Generation 2++

Window: SWIR, LWIR
Material: InGaAs, VOx, Amorphous Si (Uncooled); MCT, QWIP (Cooled)
Format: Staring arrays (320 x 256, 640 x 512)
Element Size: 20-25µm





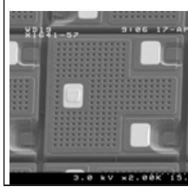


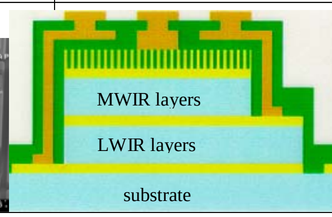
Third Generation

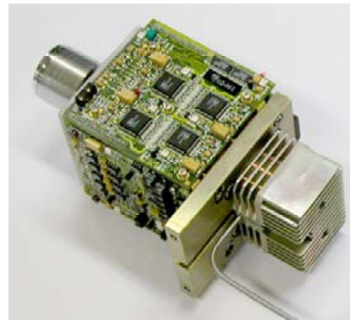
Window: Dual band/ colour
Material: MCT, InSb
Format: Larger Staring arrays (1K x 1K)
Processing : On chip processing
Cooling: Cooled/Uncooled
Element Size: 15 µm

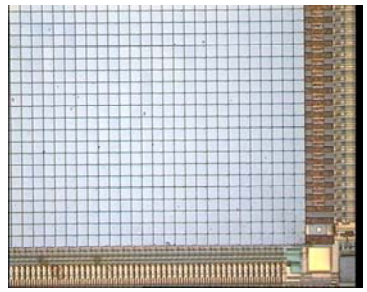
DUAL-BAND QWIP

format	288 x 384 x 2
pitch	40 µm
λ_1 (peak)	4,8 µm, pc hqe QWIP
λ_2 (peak)	8,0 µm pV QWIP
fillfactor	81 %
analogue outputs	8 $\rightarrow$ 4 per band
read out mode	snap shot; stare then scan
charge handling	14 Mio e^-
full frame rate @384x288	50 Hz @ T_{int} = 16,8 ms 100 Hz @ T_{int} = 6,8 ms
T_{op}	61 K
biasing	individual for both bands

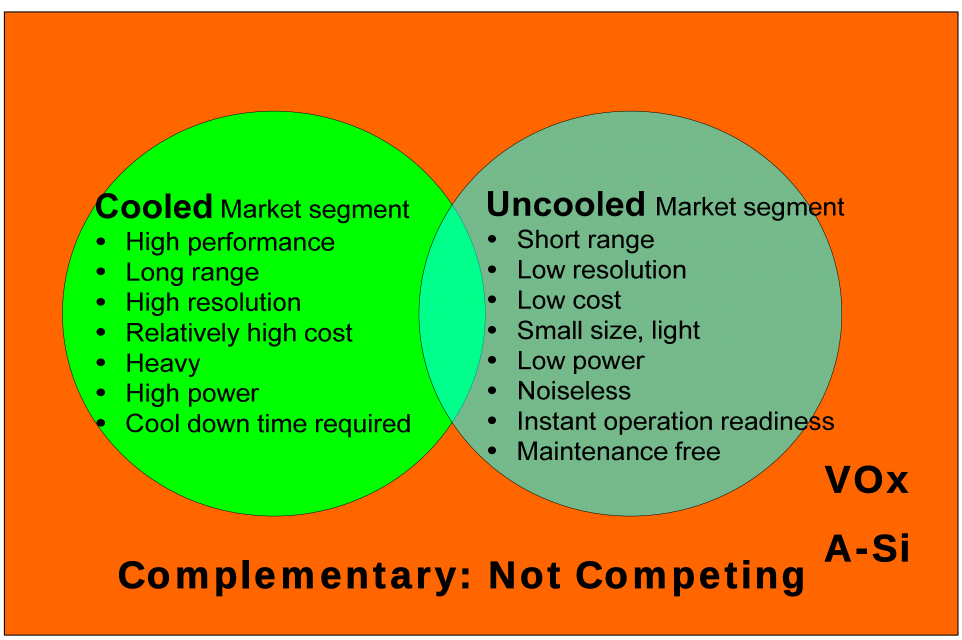








Detectors – Enabling Technology



ADVANCES IN UNCOOLED SENSORS

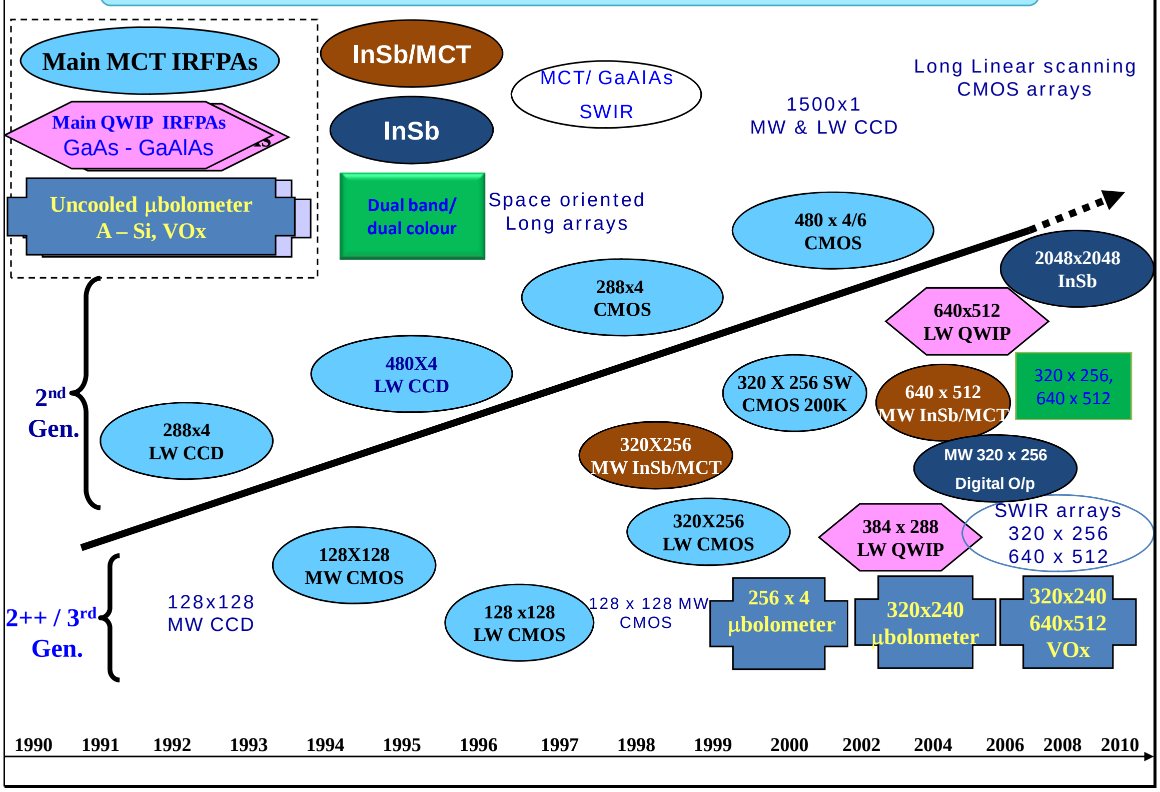
	2008 →	2020	
High Performance	NEΔT ~ 40 mK (f/1, 60 Hz) 25 µm pixel 640x480 $15 K	NEΔT ~ 5 mK (f/2, 400 Hz) 25 µm pixel HDTV $ 1 K	•Defence Against Airborne Threats
Low cost, size	NEΔT ~ 70 mK (f/1, 30 Hz) 25 µm pixel 320x240 $10 K	NEΔT ~ 10 mK (f/2, 60 Hz) 25 µm pixel 640 x 480 $ 100	•Surface Based Systems

HMTI

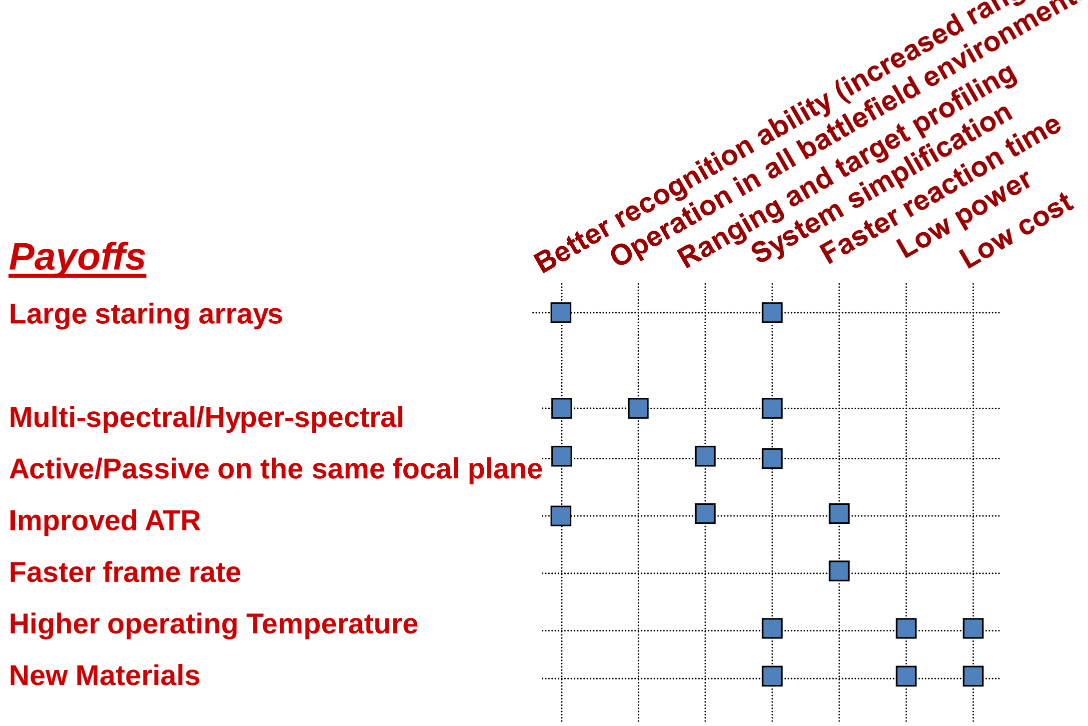
RIFLE SIGHTS

MISSILES

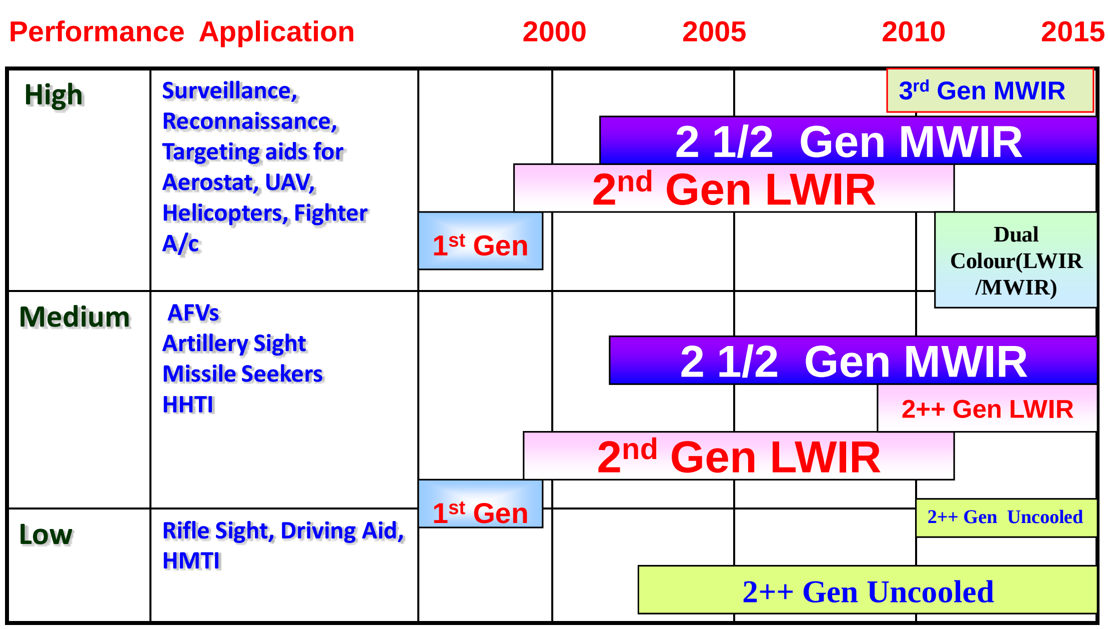
IR DETECTOR EVOLUTION



NEXT GENERATION IR SENSORS



INFRARED IMAGER TECHNOLOGY ROADMAP



SWIR Systems

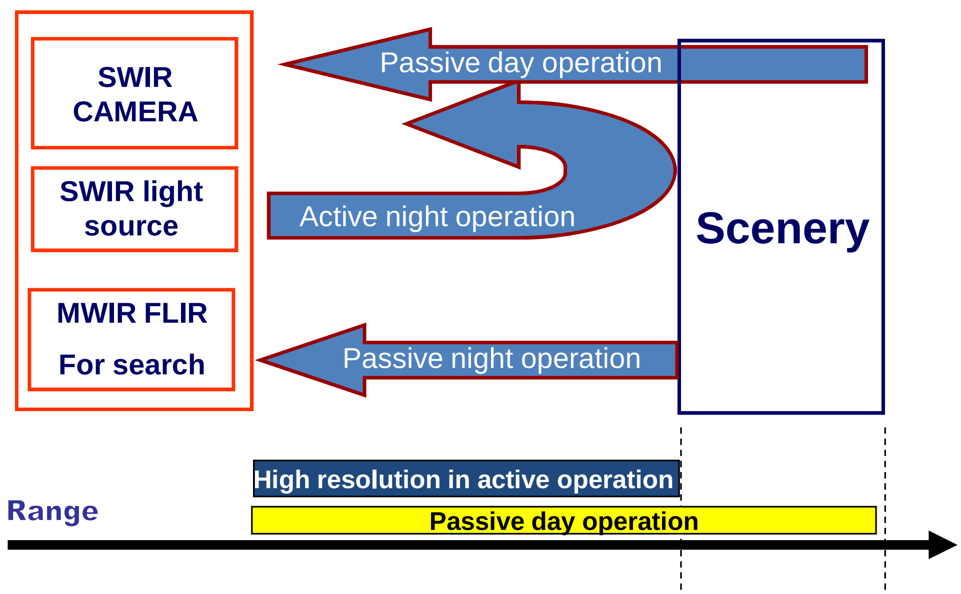
(0.9-2.5 µm)

Advantages

- Improved atmospheric transmittance
- Improved resolution
- Reflective image improves picture understanding
- Distinction between friend and foe.
- Camouflage detection
- Landing strip runway lights, which have peak emission in SWIR band.

SWIR Systems

System Principle Architecture



SWIR Systems

Improved picture understanding

MWIR

SWIR

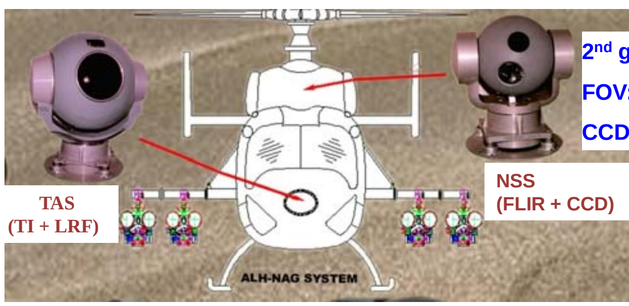
Electro-Optical Payloads

2nd gen Thermal Imager

FOV: 8 x6 /2.2 x1.6

Recognition Range: 4 Km

LRF : Km



2nd gen Thermal Imager

FOV: 16 x12 /8 x6

CCD camera range: 4 Km

EOFCS NAVITIS

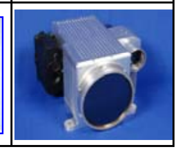
Salient Features

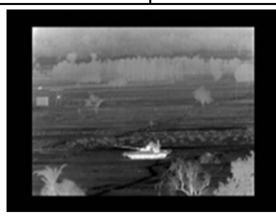
Thermal Imager
- **Type** : 2^{nd} gen
- **Spectral Band** : 7.7 –10.5 µm
- **FOV** : 8° x 6 ° (W)
  : 2.2 ° x 1.6° (N)
- **Detector** : 288X4 MCT LFPA
- **Range (Ship)**
  Detection : 16 Km
  Recognition : 12 Km

CCD Camera
- **FOV** : 27X continuous zoom
  : 34.5° x 25.7° (W)
  : 1.4 ° x 1.0° (N)
- **Range (Ship)** : Detection : 20 Km
  : Recognition : 15Km

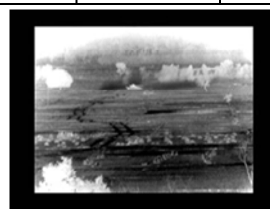
LRF
- **Type** : Nd-YAG
- **Wavelength** : 1.064 µm
- **Range** : 20 Km 5m

Infrared Imaging Systems

Parameters\ Product		HHTI	MRTI	LRTI	CTI for T-72	HMTIC	TI for NAMICA
FOV	NFOV	3.2 x2.4	2.3 x 1.7	1.5 x 1.1	7.4ºx5.4º	-	2.2 x 1.65
	WFOV	9.6 x7.2	4.6 x 3.4	8 x 6	3.7ºx2.7º	45 X34	8 X 6
Resolution (μrad)		175	125	83	200	-	-
Recognition Ranges		2.0 Km (NATO target)	3.5 Km (NATO target)	17 Km (Ship Target)	2.8 Km Tank target	50m (Human target)	4 Km
							

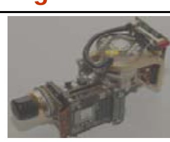


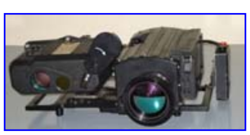
600 m



1600 m

Low Cost Infrared Imaging Systems

Parameters	Product Specifications
FOV	2.6° x2.0°
Resolution (μrad)	140
Recognition Ranges	3.0 Km for NATO target
 SWAN Detector	 



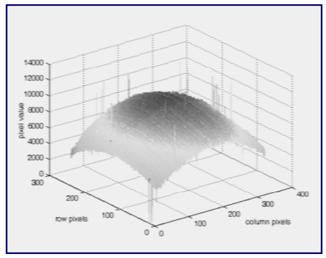
Proto sight integrated with LRF for GMD MKIII

Proto sight integrated with AMR

Proto sight integrated with CDU for BFSR

Non-Uniformity Compensation Results

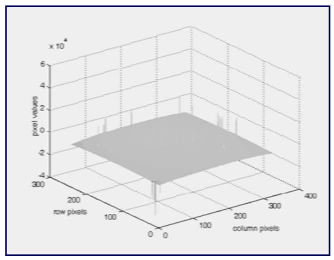
(a) NUC Pattern



3-D plot of (a)

Raw Image

(b) After NUC of Pattern

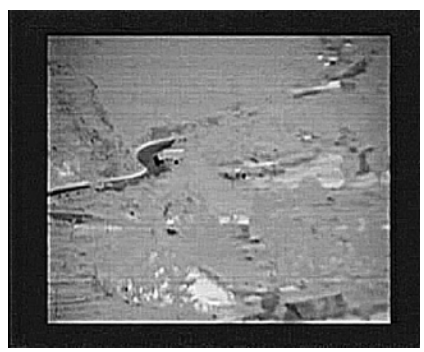


3-D plot of (b)

Image after NUC

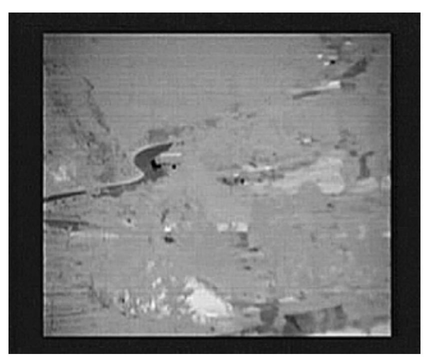
IMAGE ENHANCEMENT RESULTS

Original Image



(c) Edge Enhancement

(a) Edge Enhancement



(b) Edge Enhancement

Infrastructure

NVDs Test Facility

IR System Test Equipment

Single Point Diamond Turning Machine

Laser Interferometer

3-Axis Rate Table

AIRBORNE STABILISED PAYLOADS

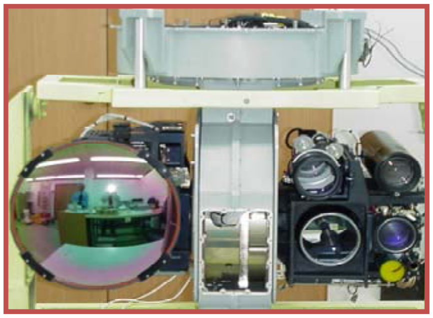
The MSSP-1/MSSP-3 Multi-Sensor Stabilized Payload is a rugged Day/Night Surveillance system especially configured for use on attack helicopters

The DSP-1 High Resolution dual sensor stabilized payload is a compact Day/Night observation system especially configured for use on UAVs, light reconnaissance aircraft, helicopters and marine patrol boats.

The FOX thermal imaging camera with continuous zoom lens 22.5x

EO Payload for Aerostat

TAMAM



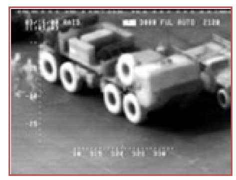
(TI + CCD+ LRF + ICCD)

WESCAM

WIDE

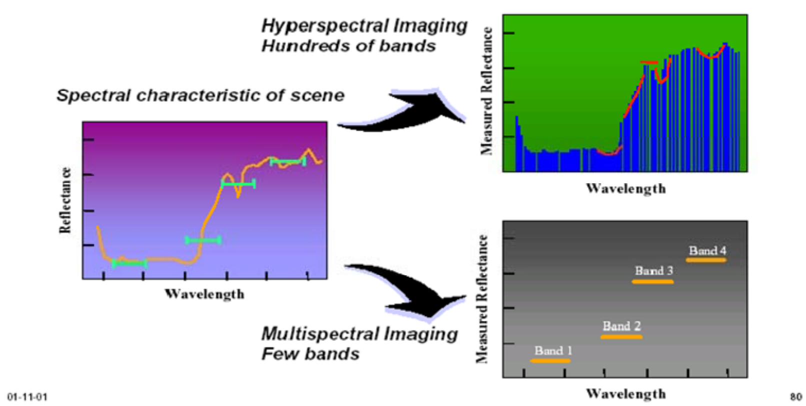
MID

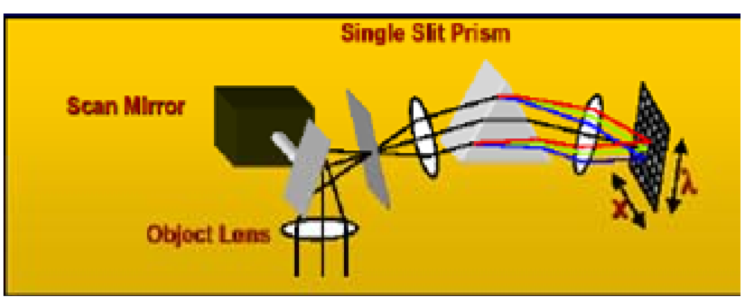
NARROW

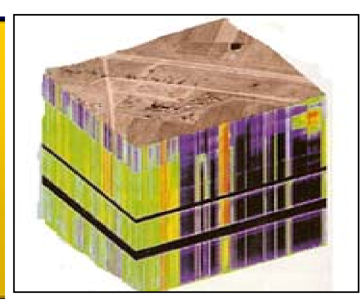


VERY NARROW

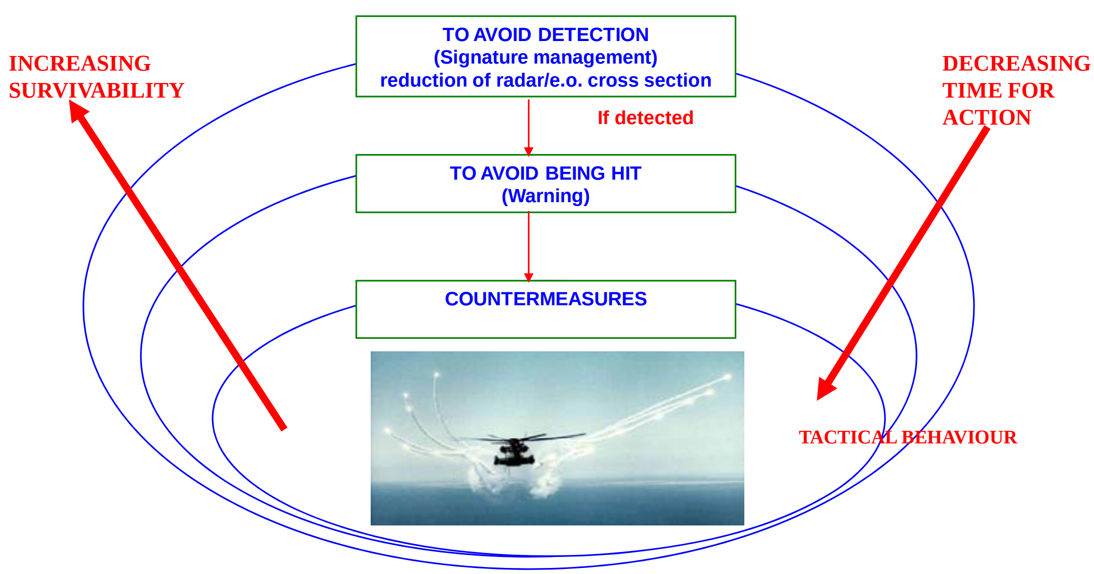
MULTISPECTRAL AND HYPERSPECTRAL IMAGER







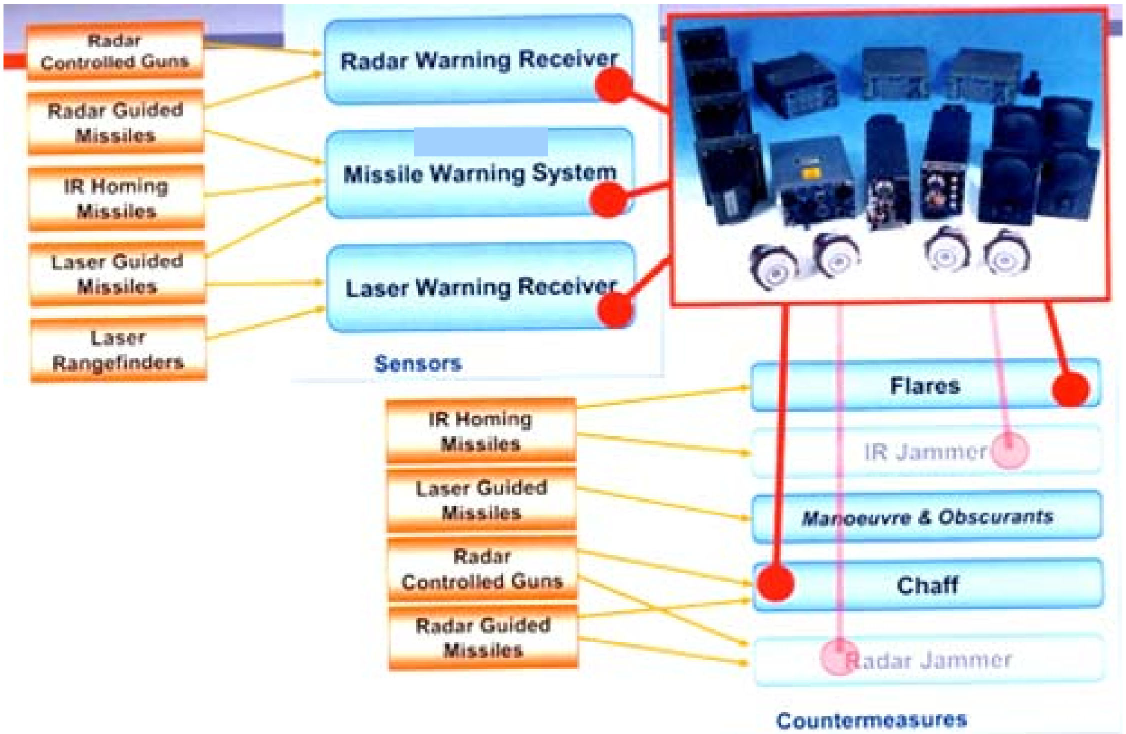
Infrared Countermeasures



Operational Platforms

(A cocktail of Technologies)

Threats – Sensors- Countermeasures



IR Countermeasure Systems

- **Flares & chaffs**
- **Add modulated infrared energy to the infrared signatures of the platform to destroy infrared guided threats.**

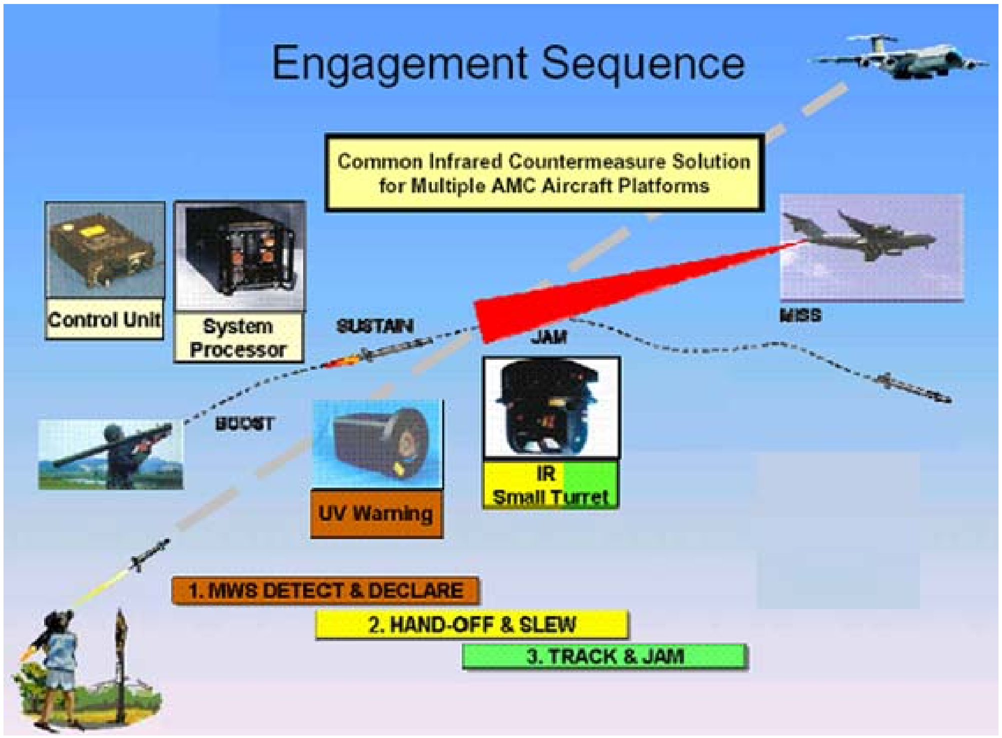
  1.Laser

  2.Directed Energy System

  To disrupt or break the lock of the seeker of the incoming missile.

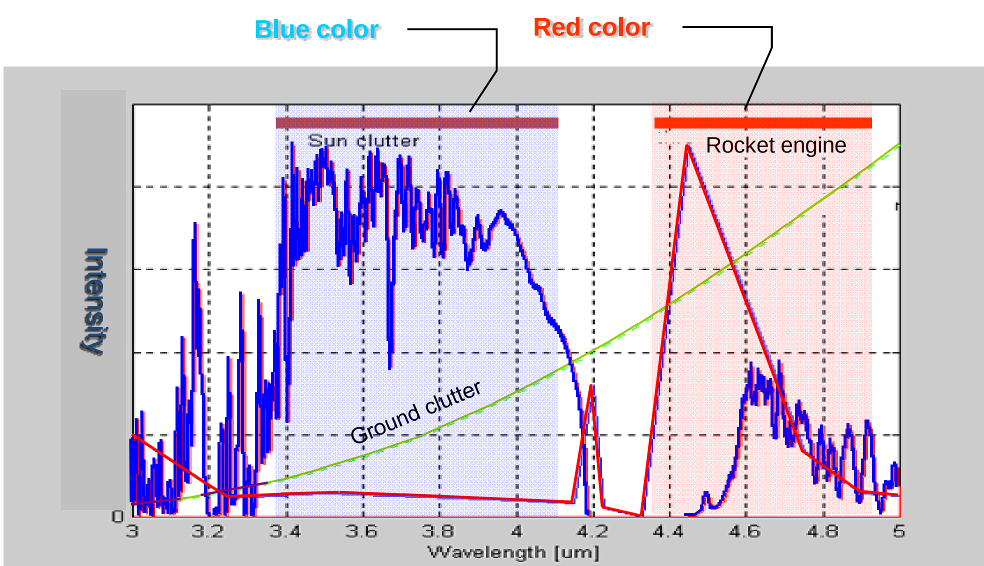
Needs The Presence

Threat Warning System

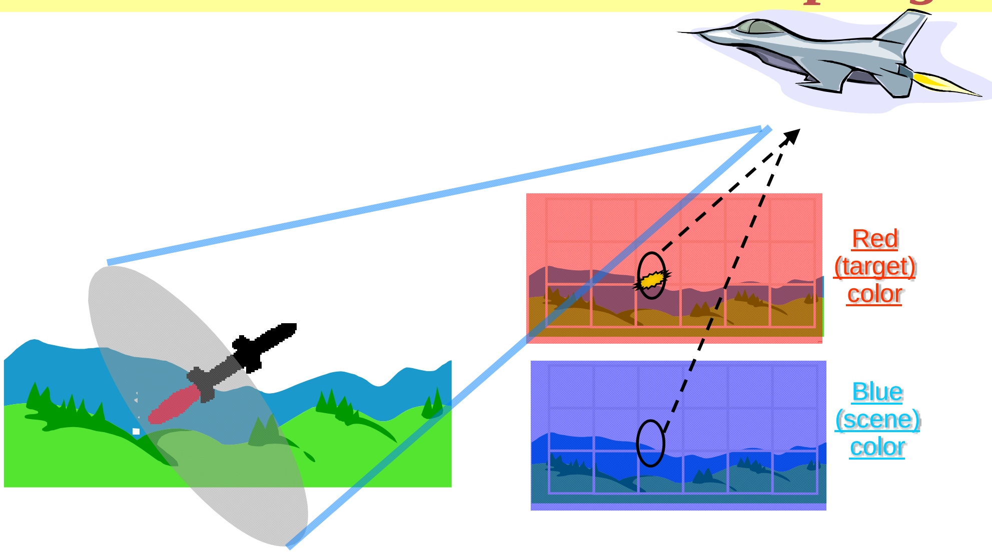


Dual color MWS

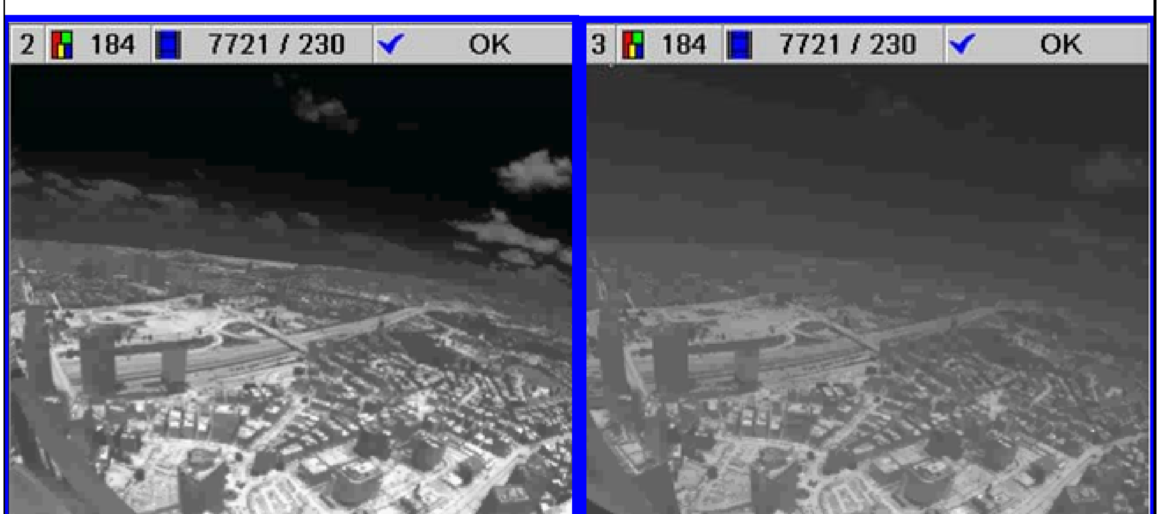
Using the spectral color signature as a filter to discriminate real missile from false targets



Two IR color simultaneous sampling



Ground Background records



Operational Improvements of DCMAWS

- **Improve system reaction time**
- **Reduces system false alarms**
- **Improved clutter rejection capability**
- **Improved system sensitivity & detection range**
- **Improved system missile detection capability**

Critical Factors :

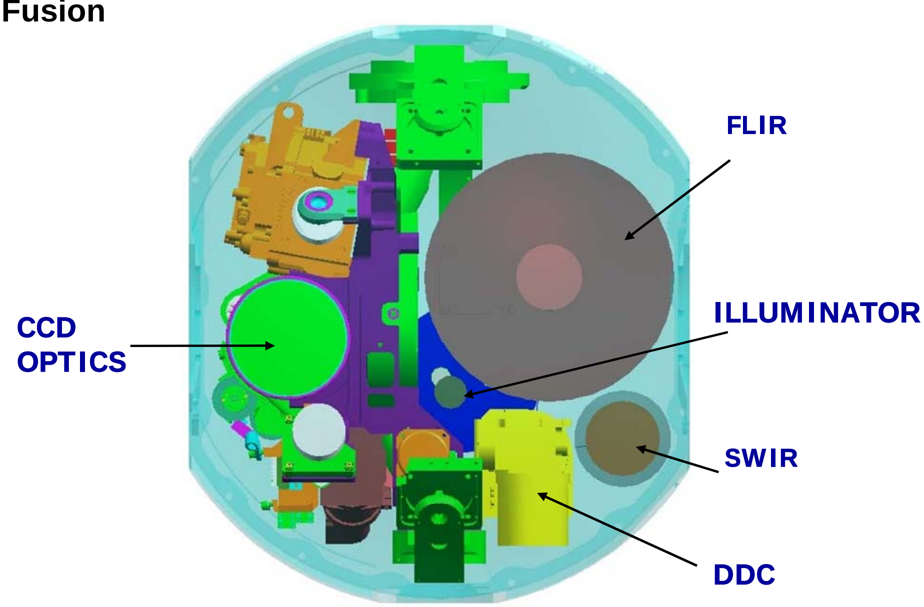
- **Simultaneous reading of data in two bands**
- **Operating the detector at higher frame rate**
- **minimum cross-talk**
- **Double processing capability**
- **Spectral separation**
- **Immune to strong heat sources like sunlight & flames**

Multiple Choices?

II NVG backed by multisensor system

MAWS

Data Fusion

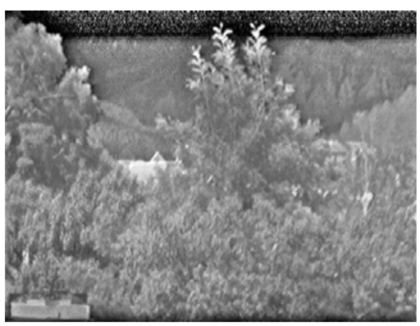


THANK YOU

Multi sensor Image Fusion

CCD Image

Thermal Image



Fused Image Using Contrast Pyramid

Dynamic Range Compression Algorithm with Plateau


Raw Image


Histogram Projection


Plateau Value = 3


Plateau Value = 5


Plateau Value = 25

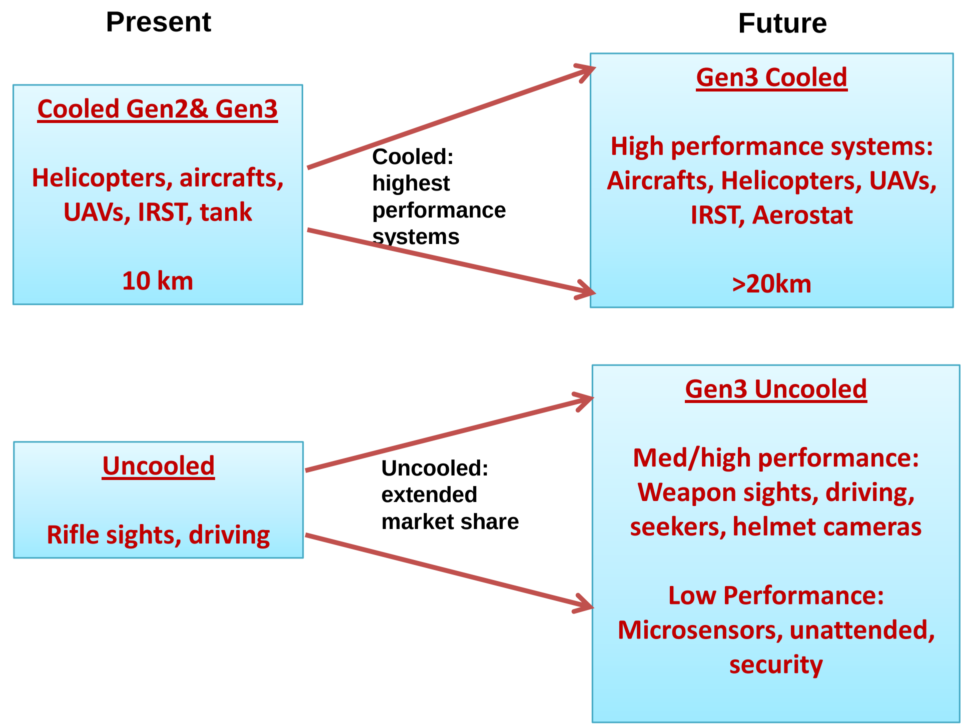

Histogram Equalization

Multi sensor Image Fusion


II CCD Image


TI Image


Fused Image



Microsensors

- **Pixel size: 50µm x 50µm (25µm for 320 x 240)**
- **Array Size: 160 x 120, possible growth to 320 x 240**
- **NETD: <50mK**
- **Input Power: <10mW**
- **Weight: <29 gms**
- **Size: < 33 cm^3**
- **Cost: expendable**

High Performance Uncooled

- **Pixel size: 25µm x 25µm**
- **Array Size: 1000 x 1000**
- **NETD: <10mK @ F/1**

	High Performance Multi-colour Cooled	High Performance Uncooled	Microsensor Uncooled
FPA	1k x 1k, 1k x 2k, 2k x 2k 18µm x 18µm	1k x 1k 25µm x 25µm	160 x 120 50µm x 50µm
Dewar	High vacuum	Moderate vacuum	Moderate vacuum
Cooler	Mechanical or TEC (120-180K)	No cooling No temperature stabilization	No cooling No temperature stabilization
Objective	Max range, greatest clutter rejection	Low cost, low power Moderate Performance	Expendable , 29gms, 10mW

	Today	Future
Type	Large format, single colour	Megapixel, multicolour
Spectral bands	MWIR/ LWIR	SWIR/MWIR MWIR/ MWIR LWIR/ LWIR LWIR
Array Size	320 x 256, 640 x 512	1k x 1k, 1k x 2k, 2k x 2k
Pixel size	25µm x 25µm	18µm x 18µm
NETD	<20mK (LWIR) 12mK (MWIR)	<1mK@F/2 (LWIR) <5mk@F/2 (MWIR)

Thermal Imaging Systems

Technology	Challenges
Optics Ge, Si New materials	Binary optics Non semiconductor, Cheaper
Photon Detectors MCT InSb QWIPs	Dual colour/ dual band detectors, Large format arrays High frame rate operation Uniformity in large arrays Higher Operating Temperature Increased Quantum Efficiency
Uncooled A-Si, VOx	Thermal sensitivity ~ 20 mK at F/4 Smaller pixel size, TEC less operation
Hyperspectral	MW & LW Operation
TE coolers	Cooling down to 120K

Speaker Profile

Dr SS Negi is Scientist ‘G’ at IRDE and is responsible for all night vision activities in the lab. He did his M.Tech in Applied Optics from IIT New Delhi in 1979 and Ph.D. on Semiconductor Devices in 2000 from HNB Garhwal University Srinagar. He joined IRDE in Dec.1980.

As Program Director he is leading a team of Scientists who have graduated from developing Ist Generation systems to 3rd Generation Thermal Imaging Systems which are finding application either as standalone surveillance system or as a part of Electro Optical Fire Control System.

He has represented IRDE as a part of defence delegation team to UK, France & Israel for identifying areas of joint collaboration. He has published 20 papers in National & International journals and is a life member of Optical Society, Semiconductor Society & Instrument Society of India.

Microwave Remote Sensing and Synthetic Aperture Radar

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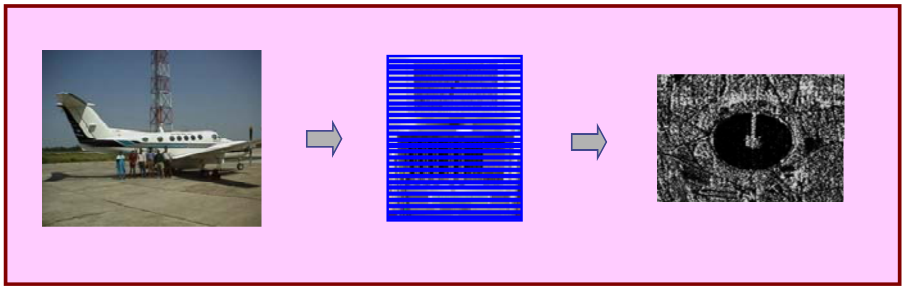
The microwave applications are playing an important role in space research. Indian Space Research Organisation (**ISRO**)/India's **Microwave Remote Sensing Programme** (**MRSP**) undergoing since 1985, involves development of microwave sensors, both active and passive, for various ground-based, airborne and civilian satellite missions. These microwave sensors have excellent capability over optical sensors to receive data in day/night as well as in all weather. Radars are the major active microwave sensors utilized for imaging purposes. Side looking airborne real aperture radar systems, the first to be utilized for such applications, suffered from the limitation of poor resolution. To increase the resolution of such a space-borne microwave sensor, which is operating at hundreds of km altitude, it would necessitate antenna dimensions between several hundred meters to some kilometers (depending on the wavelength of operation). A technique called synthetic aperture radar, is being widely utilized to overcome these problems. Synthetic aperture radar transmits pulses of microwave energy toward Earth and collects the energy that is scattered back to the antenna. The motion of the platform is used to "synthesize" an antenna (the aperture) that is much longer in length than the actual antenna. A longer antenna produces images of finer resolution. This paper will present the description of Microwave remote Sensing and Synthetic Aperture Radar (SAR) technique, which is an important element of microwave space applications.

• MICROWAVE REMOTE SENSING
• &
• SYNTHETIC APERTURE RADAR



By

Nilesh M. Desai, Scientist/Engineer-SG, Head

•MSDPD / MSDG/MRSA, Space Applications Centre,

•Indian Space Research Organisation

•Ahmedabad.

TOPICS IN THIS PRESENTATION

- Remote Sensing
- Introduction to Microwave Remote Sensing
- Radar Basics
- Synthetic Aperture Radar Basics
- SAR Processing and Image Generation Aspects
- Airborne SAR development in SAC/ISRO
- Airborne SAR for Disaster Management (DMSAR)
- Quick Look and Near Real Time Processing Systems for DMSAR
  - QLP/NRTP Processing Algorithms
  - Processor Complexity
  - Multi-Processor Architecture
- Radar Imaging Satellite (RISAT-1)
  - Introduction
  - RISAT-1 Operating Modes

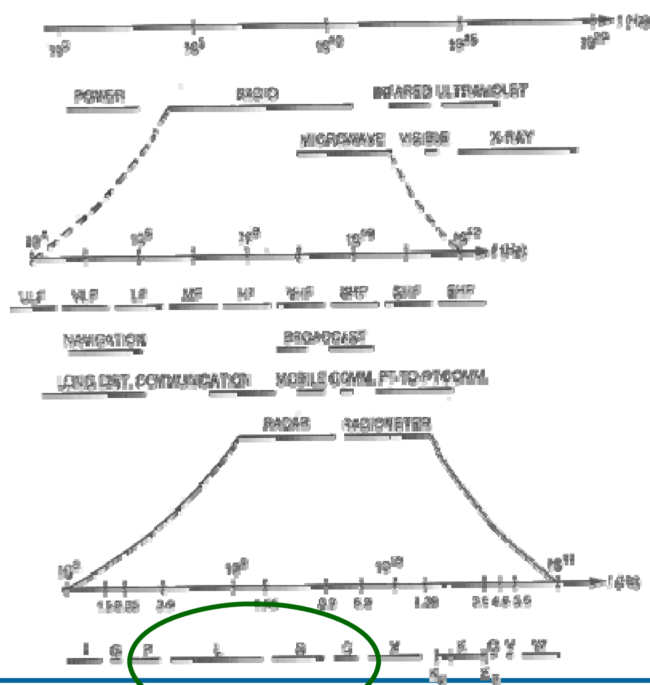
REMOTE SENSING

- **Remote sensing is defined as an art and science of obtaining information about an object by a device that is not in direct contact with it.**

TYPES OF REMOTE SENSING:

- **OPTICAL REMOTE SENSING**
  - **Visible, UV, IR (NIR / MIR / FIR)**
- **MICROWAVE REMOTE SENSING**
  - **Utilizes microwave portion of spectrum**

VARIOUS REGIONS OF ELECTROMAGNETIC SPECTRUM



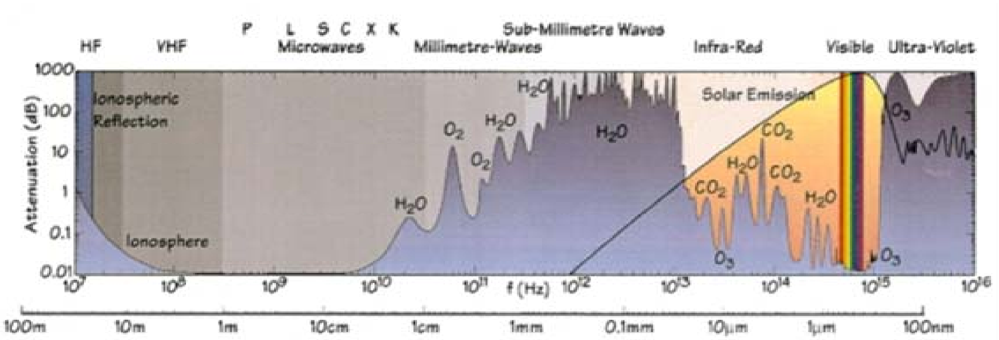
NAL, Bangalore Space Applications Centre April 26, 2008

FREQUENCY SPECTRUM

Microwave Region of the EM Spectrum

Capabilities.

- Propagation through Cloud Cover
- Independent of Sun's illumination
- Sensitivity to Moisture Content
- Penetration through Vegetation and Soil (Certain Extent)
- All Weather, Day/Night Imaging Capability

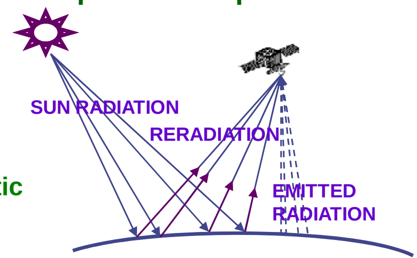


MICROWAVE SPECTRUM

BAND		FREQUENCY
UHF	-	0.3 GHz to 1.0 GHz
L	-	1.0 GHz to 1.5 GHz
S	-	1.5 GHz to 3.9 GHz
C	-	3.9 GHz to 8.0 GHz
X	-	8.0 GHz to 12.5 GHz
Ku	-	12.5 GHz to 18.0 GHz
Ka	-	18.0 GHz to 26.0 GHz

MICROWAVE REMOTE SENSING

• Microwave Remote Sensing utilizes microwave portion of spectrum



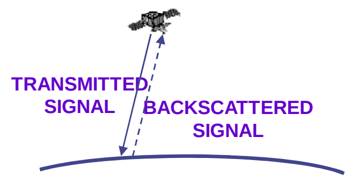
PASSIVE MICROWAVE SENSING

Detects the naturally emitted electromagnetic energy

- Radiometer – Nadir Looking, Scanning, Synthetic
- Microwave Sounders – Limb sounder

ACTIVE MICROWAVE SENSING

Own source of microwave radiation to illuminate the target

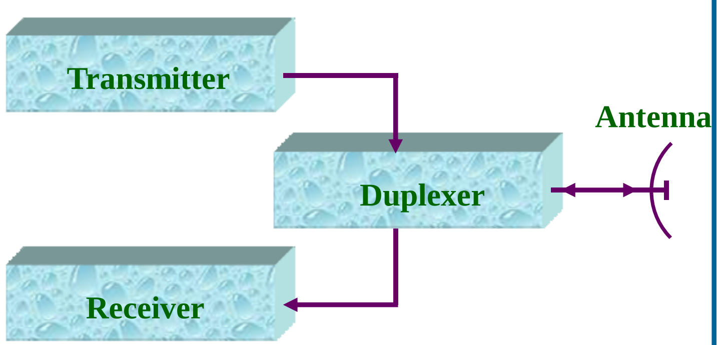


- Imaging
  - SAR (Synthetic Aperture RADAR)
- Non-Imaging
  - Altimeter – Nadir Looking, Pulse Limited, Beam Limited, Aperture Synthesis
  - Scatterometer – Pencil Beam, Fan Beam

RADAR

RADAR consists of:

- Transmitter
- Receiver
- Antenna



Block Diagram of an elementary pulsed radar

POLARIZATION

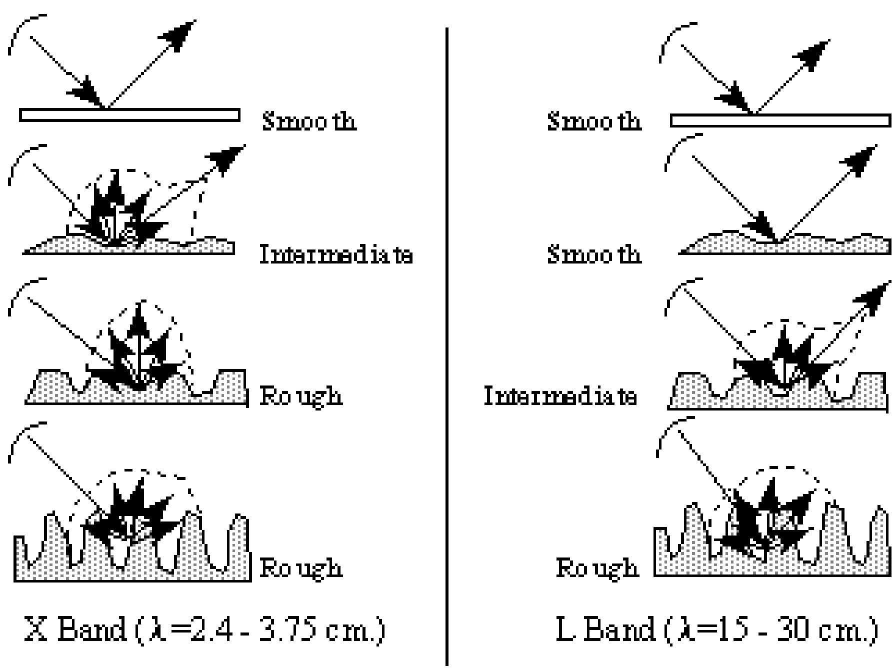
Like-Polarized

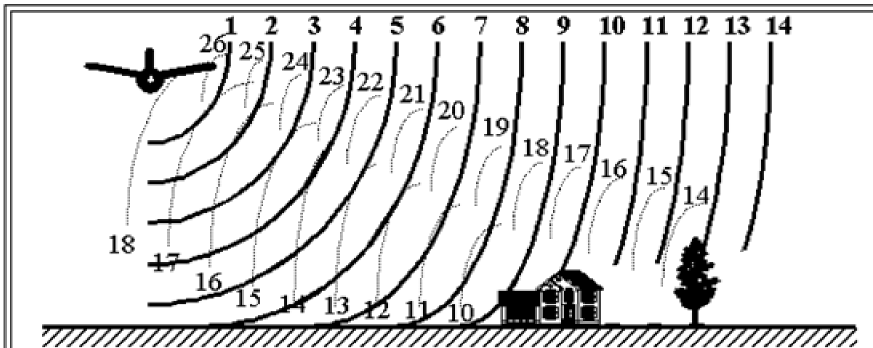
- **HH - for horizontal transmit and horizontal receive,**
- **VV - for vertical transmit and vertical receive,**

Cross-Polarized

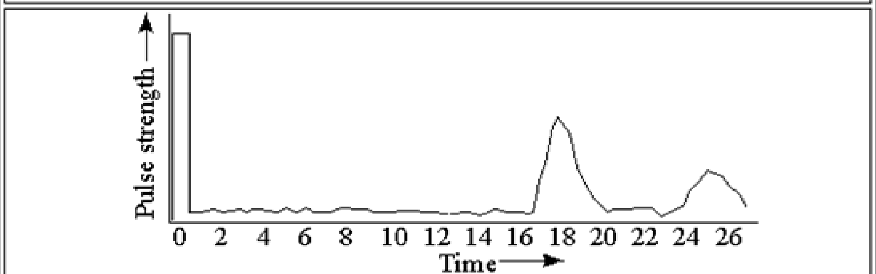
- **HV - for horizontal transmit and vertical receive, and**
- **VH - for vertical transmit and horizontal receive.**

RADAR BACKSCATTERING AT DIFFERENT SURFACES

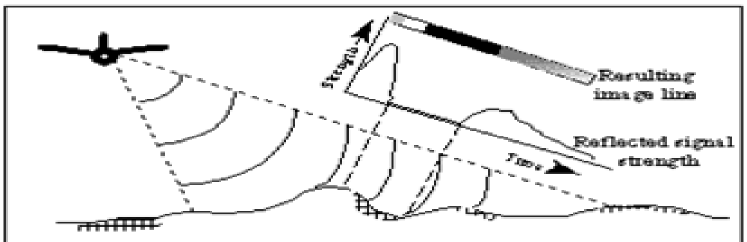




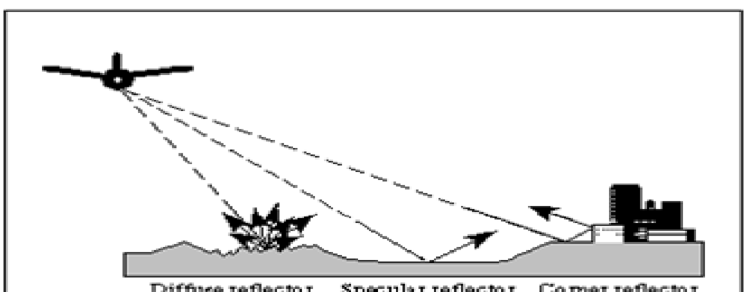
Propagation of one radar pulse (after Drury, 1990; Lillesand and Kiefer, 1994)



Resulting antenna return (after Drury, 1990; Lillesand and Kiefer, 1994)



Effect of sensor/terrain geometry on SLAR imagery.
(Lillesand and Kiefer, 1994)



Radar reflection from various sources (Lillesand and Kiefer, 1994).

PRINCIPLES OF IMAGING RADAR
REAL APERTURE RADAR

- **Side Looking RADAR to avoid ambiguities**
- **Range Resolution**

$$X_r = \frac{c\tau}{2\sin\theta} = \frac{c}{2BW\sin\theta}$$

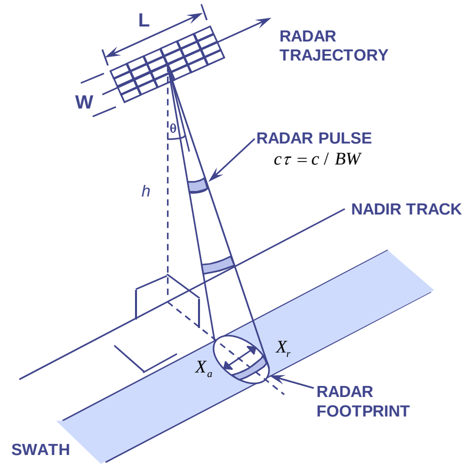
- **Azimuth Resolution**

$$X_a = \frac{h\lambda}{L\cos\theta}$$

- **Swath Width**

$$S = \frac{h\lambda}{W\cos^2\theta}$$

$$\left.\begin{array}{r} h = 800\text{ km} \\ \lambda = 24\text{ cm} \\ BW = 20\text{ MHz} \\ \theta = 35^\circ \end{array}\right\} \Rightarrow \begin{array}{l} X_r = 13\text{ m} \\ X_a = 20.5\text{ km} \end{array}$$



PRINCIPLES OF RADAR IMAGING
SYNTHETIC APERTURE RADAR

Because the radar is moving relative to the target, the received signal will be shifted in frequency relative to the transmitted frequency by an amount

$$f_d = \frac{2v}{\lambda}\sin\phi$$

Targets ahead of the radar will have positive Doppler shifts, and those behind the radar have negative Doppler shifts.

- Range Resolution:

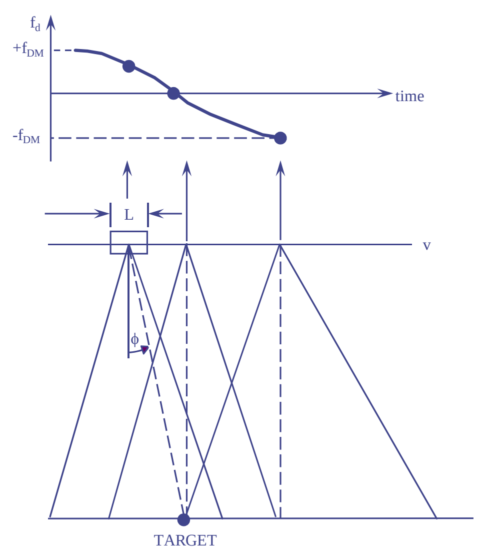
$$X_r = \frac{c}{2BW\sin\theta}$$

- Azimuth Resolution

$$X_a = \frac{v}{2f_{DM}} = \frac{L}{2}$$

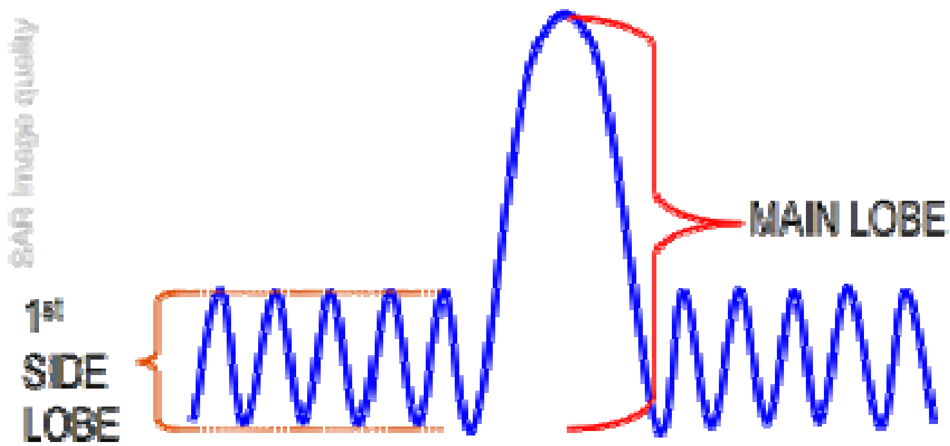
- Swath Width:

$$S = \frac{h\lambda}{W\cos^2\theta}$$

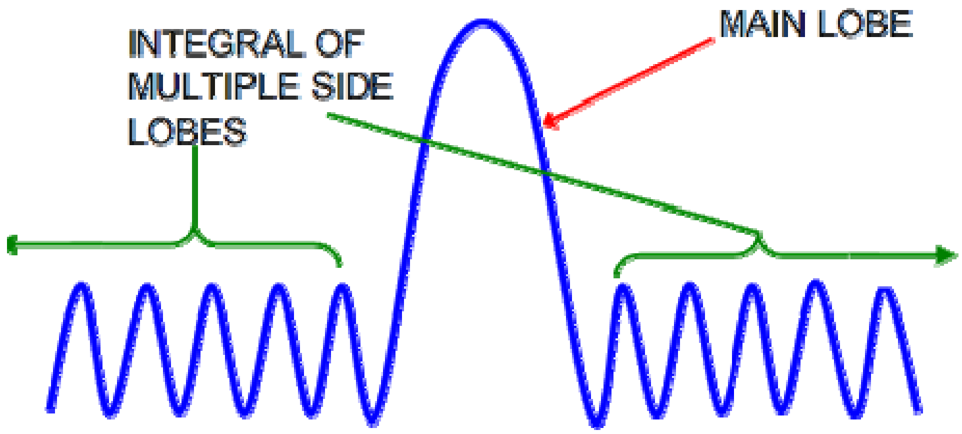


BOTH RANGE AND AZIMUTH RESOLUTIONS ARE INDEPENDENT OF DISTANCE TO TARGET!

- Peak to Side Lobe Ratio – Ratio between the returned signal of the main lobe and that of the first side lobe of the point target.



- Integrated Side Lobe Ratio – Ratio between the returned energy of the main lobe and that integrated over several (usually 10-20) lobes on both sides of the main one



SYNTHETIC APERTURE RADAR (SAR)

A class of high resolution RADAR, which obtains fine angular resolution by coherent processing of backscattered Doppler histories.

SAR OPERATING MODES

- **STRIPMAP MODE**
- **SCANSAR MODE**
- **SPOTLIGHT MODE**

AIRBORNE vs SPACEBORNE

Spatial resolution is independent of platform altitude

Fine resolution can be achieved from both

DECIDING FACTORS

- **The Extent of area to be covered**
- **The speed of the phenomenon to be observed**
- **Detailed performance of the instrument available for flying in the aircraft or satellite**
- **Availability and cost of data**

GLOBAL SAR SYSTEMS

- RADARSAT-1, RADARSAT-2, Canada
- ENVISAT-1, ESA
- SIR-C / X-SAR, USA
- SEASAT-A, USA
- ALMAZ-1, Russia
- TERRASAR-X, GERMANY
- TECSAR, ISRAEL
- RISAT-1, India (2009 AD Launch)

- ASAR, DMSAR- INDIA
- INTERRA SAR, CANADA
- ELTA SAR, ISRAEL
- E-SAR, DLR/GERMANY

APPLICATIONS

- Defense and Military
- Geology (Surveys, Minerals Resources)
- Land Use (Urban, agriculture, soil survey, crop health, moisture and yield prediction, wildlife, forestry-inventory)
- Water Resources (Supply, Pollution, underground, snow & Ice mapping)
- Coastal Study (erosion, accretion, bathymetry, sewage, thermal and chemical pollution monitoring)
- Oceanography (waves & currents circulations, mapping of sea ice)

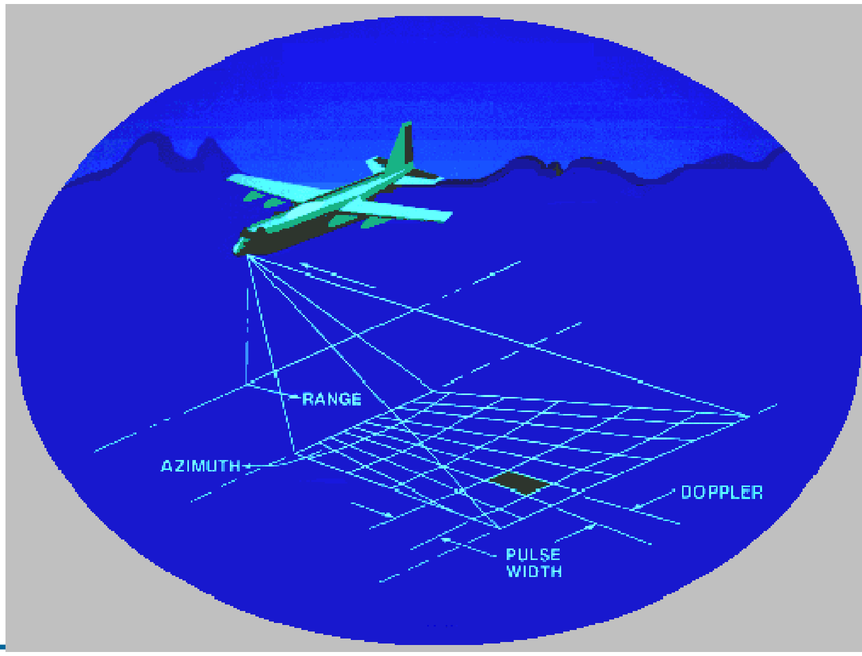
APPLICATIONS (Cont..)

- **Meteorology (weather system tracking, forecasting, clouds classification)**
- **Natural Disasters (floods, earth quacks, volcanoes, forest fires, subsurface coal fires, land slides)**
- **Planetary studies and Astronomy**
- **Climatology**

INTRODUCTION TO SAR
(SYNTHETIC APERTURE RADAR)

- **GENERATES HIGH-RESOLUTION AERIAL PHOTOGRAPH-LIKE IMAGES**
  - IMAGE RESOLUTION RANGES FROM (50 x 50)M DOWN TO (0.5x0.5)M
- **APPLICATIONS (BOTH COMMERCIAL AND MILITARY)**
  - GROUND SURVEILLANCE (ALL WEATHER;DAY OR NIGHT)
  - TERRAIN MAPPING
  - OBJECT IMAGING (INVERSE SAR / ISAR)
- **REQUIRES RELATIVE MOTION BETWEEN RADAR PLATFORM AND AREA BEING IMAGED**
  - AIRBORNE SAR
  - SATELLITE SAR (IMAGING OF EARTH AND PLANETARY TERRAIN)
  - ISAR (IMAGING OF SATELLITES BY GROUND RADARS)

AIRBORNE SAR GEOMETRY



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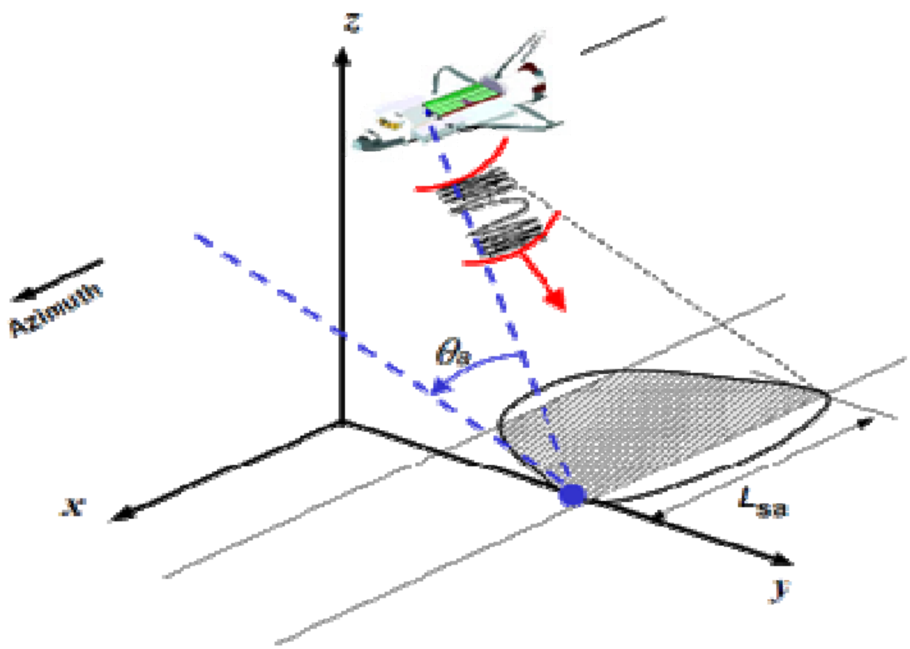
AIRBORNE SAR IMAGING GEOMETRY



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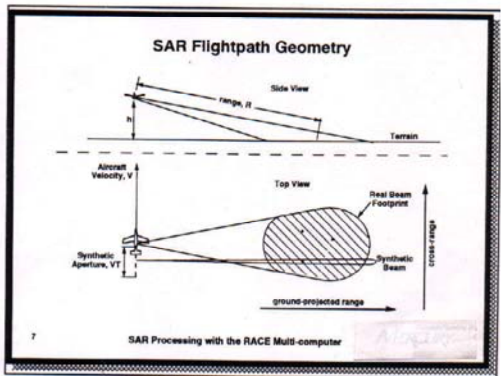
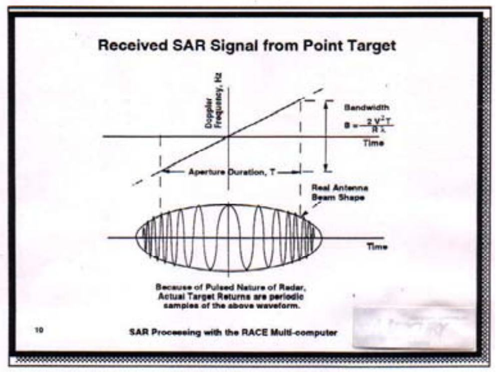


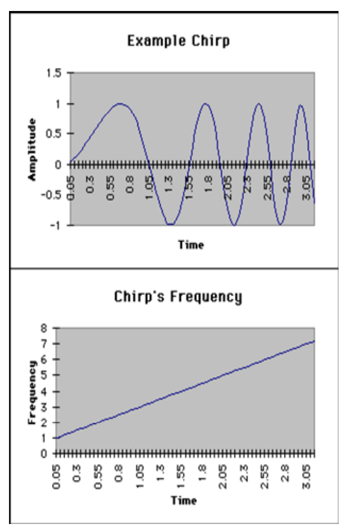


SYNTHETIC APERTURE RADAR BASICS

- Range Resolution = C x Pulse Width/2
- Chirp signal increases pulse length and range resolution
- Range Resolution obtained by pulse compression

$\Delta R = C/(2B)$

B – Bandwidth of Chirp signal
C – Velocity of light



SYNTHETIC APERTURE RADAR BASICS (cont.)

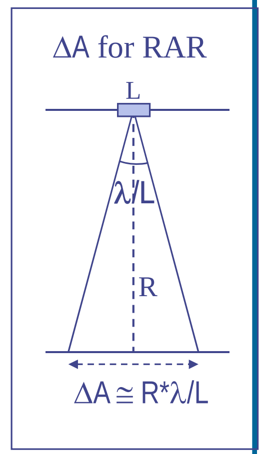
- Azimuth resolution of RAR (Real Aperture Radar) is determined by foot print on ground

$$\Delta A = R^*\lambda/L$$

- Azimuth resolution of Synthetic Aperture Radar

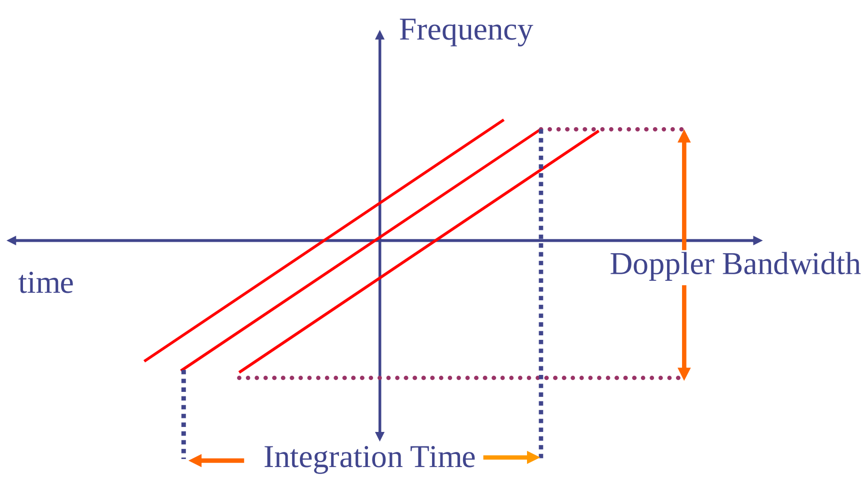
$$\Delta A = L/2$$

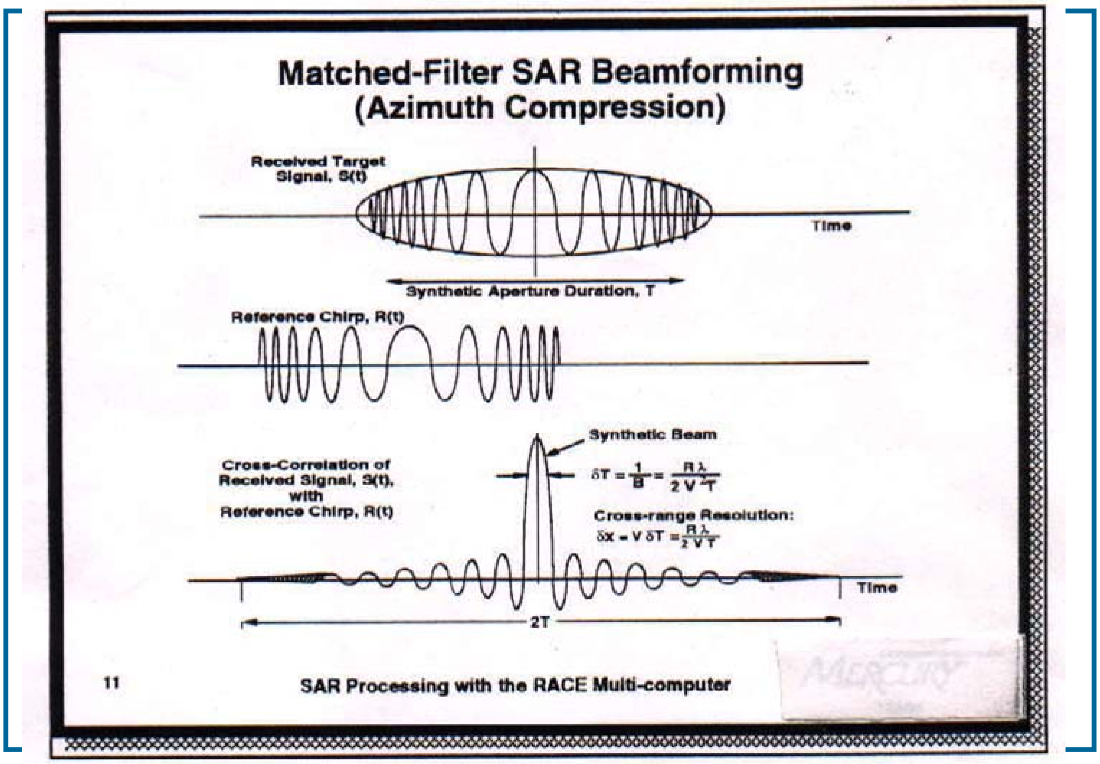
R - Slant Range of the target
λ - Wave Length
L - Length of the antenna



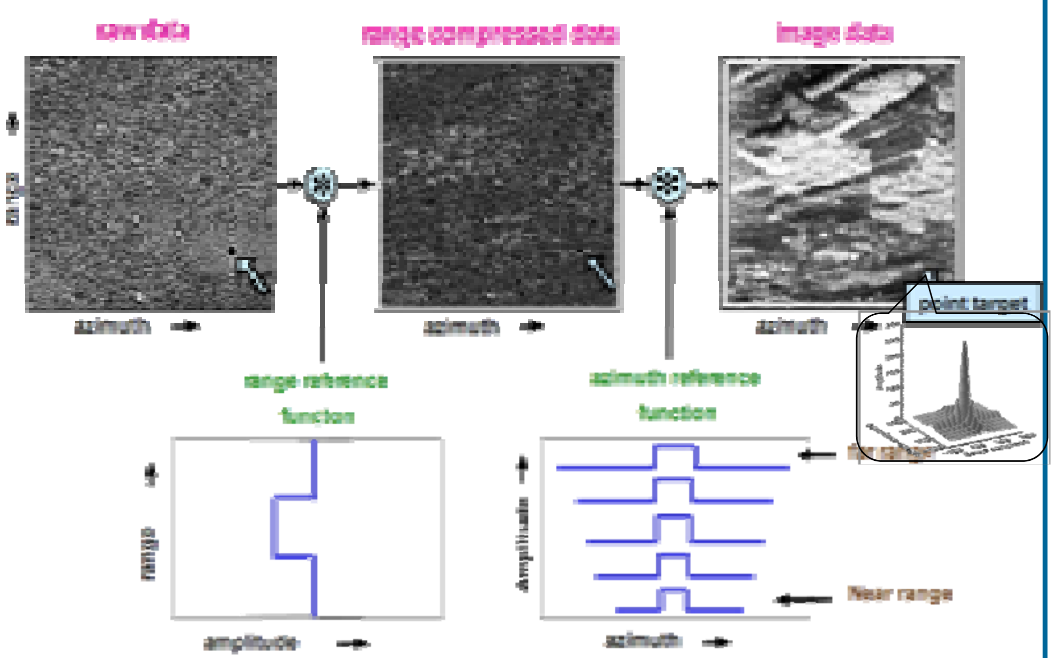
SYNTHETIC APERTURE RADAR BASICS (cont.)

Synthetic Aperture radar achieves better cross – range (Azimuth) resolution by identifying the targets based on their Doppler shift

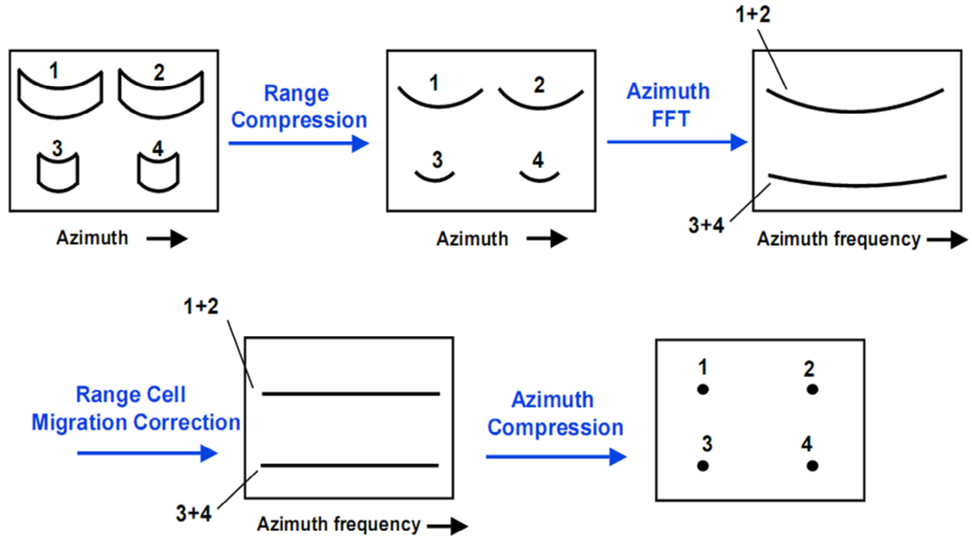


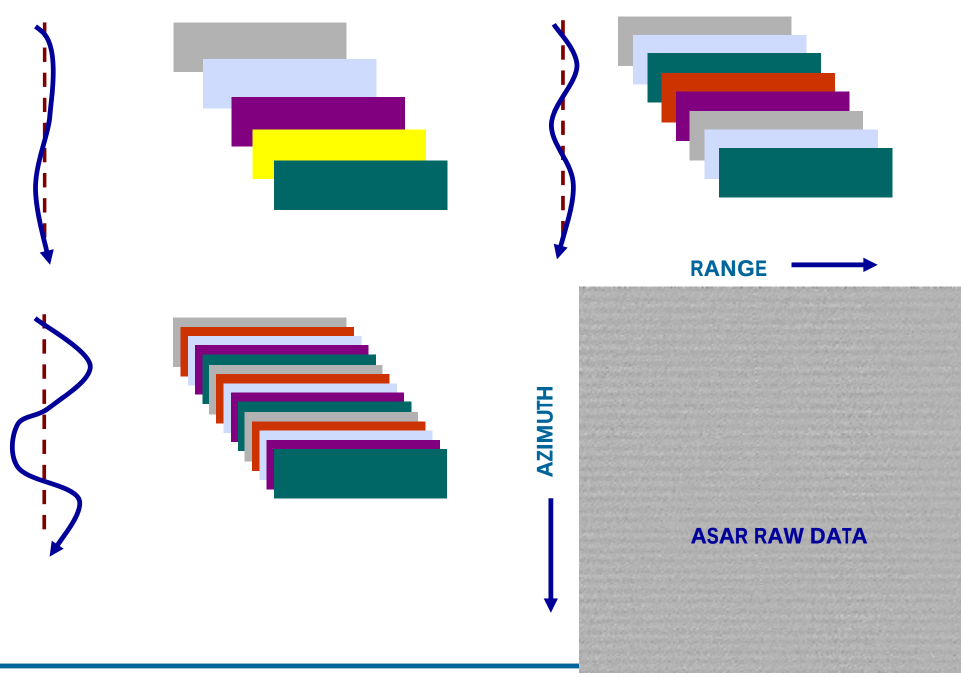


BASIC SAR PROCESSING STEPS



BLOCK SCHEMATIC OF RANGE DOPPLER ALGORITHM





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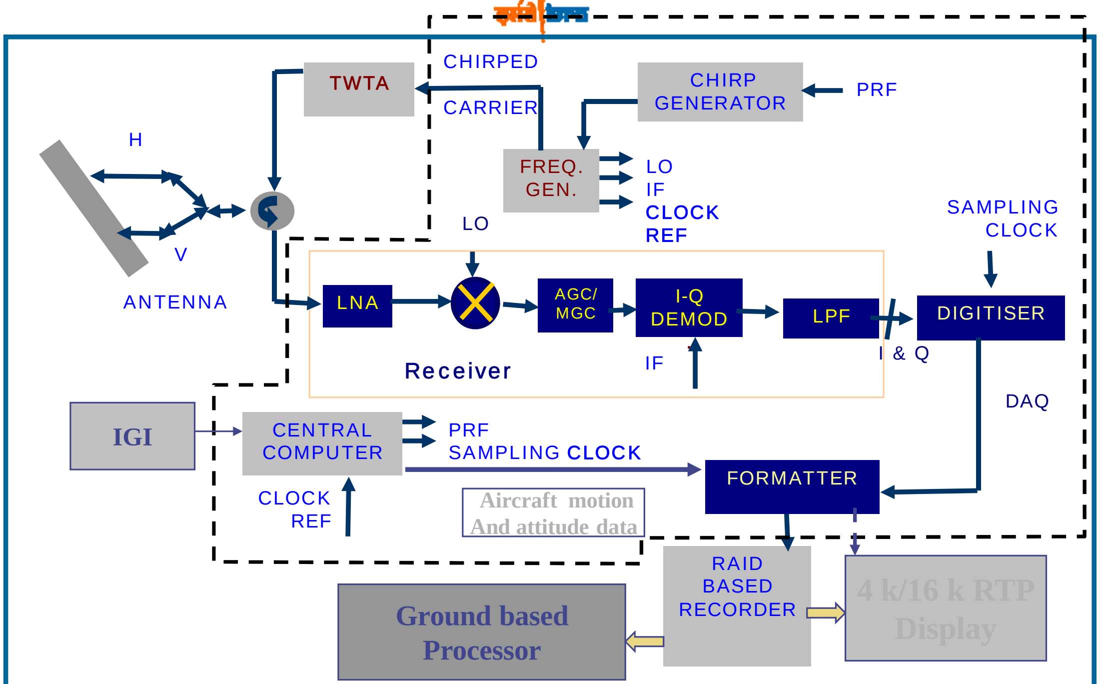
Airborne SAR development in SAC/ ISRO

- Since 1985, SAC/ISRO has been working on **Microwave Remote Sensing Program (MRSP)** under which development of microwave sensors for various ground based, airborne and civilian satellite missions is being carried out
- In 1990s, a C – band Airborne imaging SAR **(ASAR)** has been developed indigenously
- ASAR, mounted on a Beech-craft 200 aircraft, generates image with ~8-10 metres resolution and having 20-25 Kms swath
- Real Time Signal Processor and Display (RTPD) system based on Motorola's DSP56001 fixed point Digital Signal Processor (DSP) was developed and was subsequently upgraded using Analog Device's ADSP – 21020 floating point DSP

- **A multimode C-band SAR (DMSAR) with variable swath/resolution has been developed and test flights were conducted in successfully in December,2005**
- **A Quick Look Processor onboard the aircraft produced real time limited swath images**



BASIC ARCHITECTURE OF DMSAR SYSTEM

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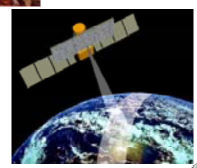
MICROWAVE REMOTE SENSING ACTIVITIES AT SAC/ISRO

SAMIR 1978/81

ASAR 1989-2002

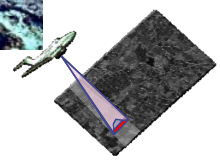
OCEANSAT TECHNOLOGY DEVELOPMENT 1994-1997

MSMR 1996-1999



RISAT 2008

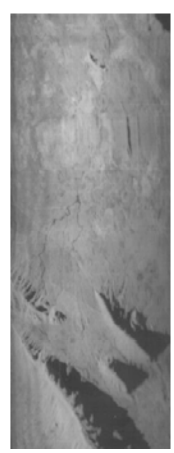
MEGHA-TROPIQUES 2000-2007

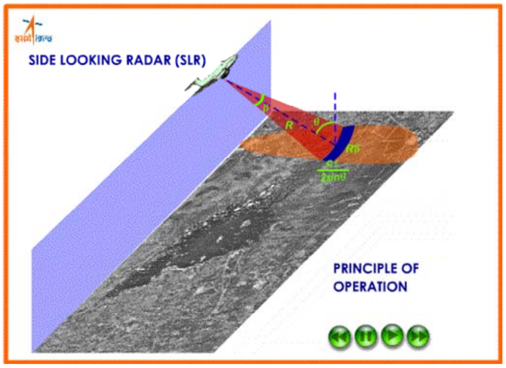


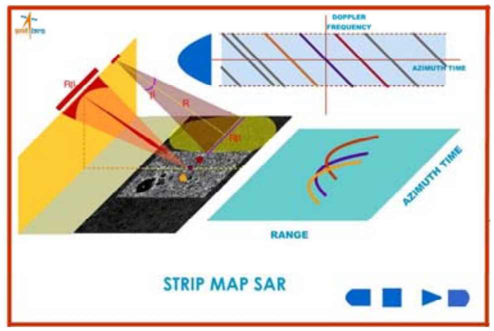
DMS SAR

X-BAND SLAR DEVELOPMENT (1983-1989)

- 9.6 GHZ, HH
- 25 KW PEAK POWER
- ALTITUDE 3 KM
- SWATH 5 KM
- PLATFORM DAKOTA DC-10







C-Band ASAR
FIRST FLOWN ON MAY 20 1992

Operating frequency	5300 MHz
Polarisation	HH, VV
Antenna pattern	Cosec^2
Back scattering coefficient	-30 to +7 dB
Instantaneous dynamic range	~ 20 dB
Slant range resolution	6 m
Azimuth resolution	6 m
Radiometric resolution	$\leq$ 2.5 dB
Swath coverage	25 Km

C-Band Airborne SAR

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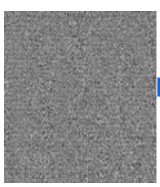
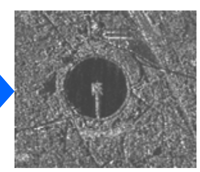
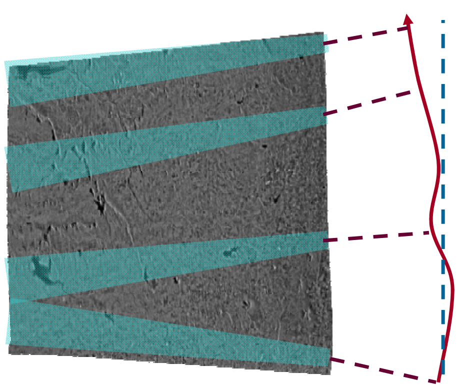
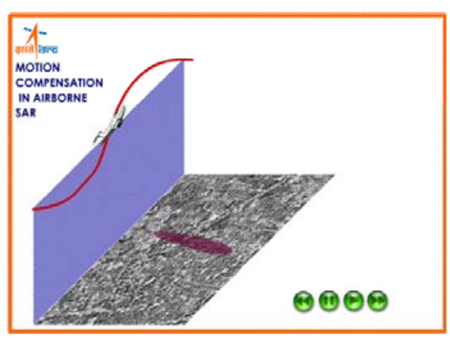


ASAR PROCESSOR (2000-2001)

- ON GROUND MOTION SENSING AND COMPENSATION
- CAN GENERATE IMAGES IN LARGE DISTURBANCES
- ENABLED REDUCTION IN ON-BOARD HARDWARE SIGNIFICANTLY
- GENERATED MUCH IMPROVED UNDERSTANDING OF SAR PROCESSING







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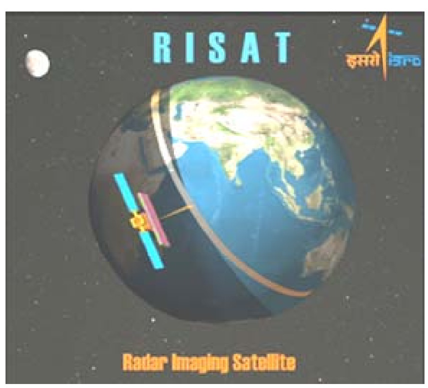
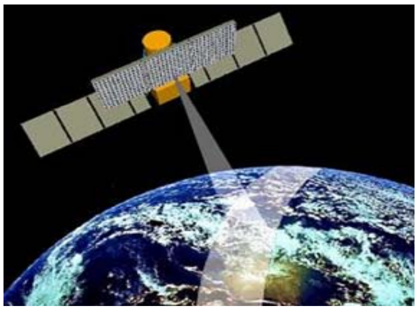
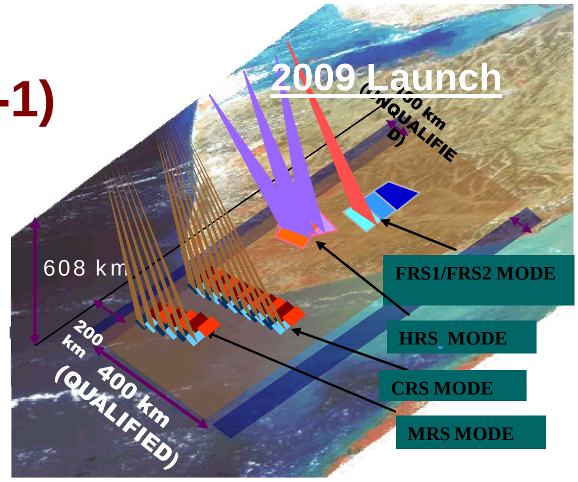
SAR Payload Of Radar Imaging Satellite-1 (RISAT-1)



RADAR IMAGING SATELLITE (RISAT-1)





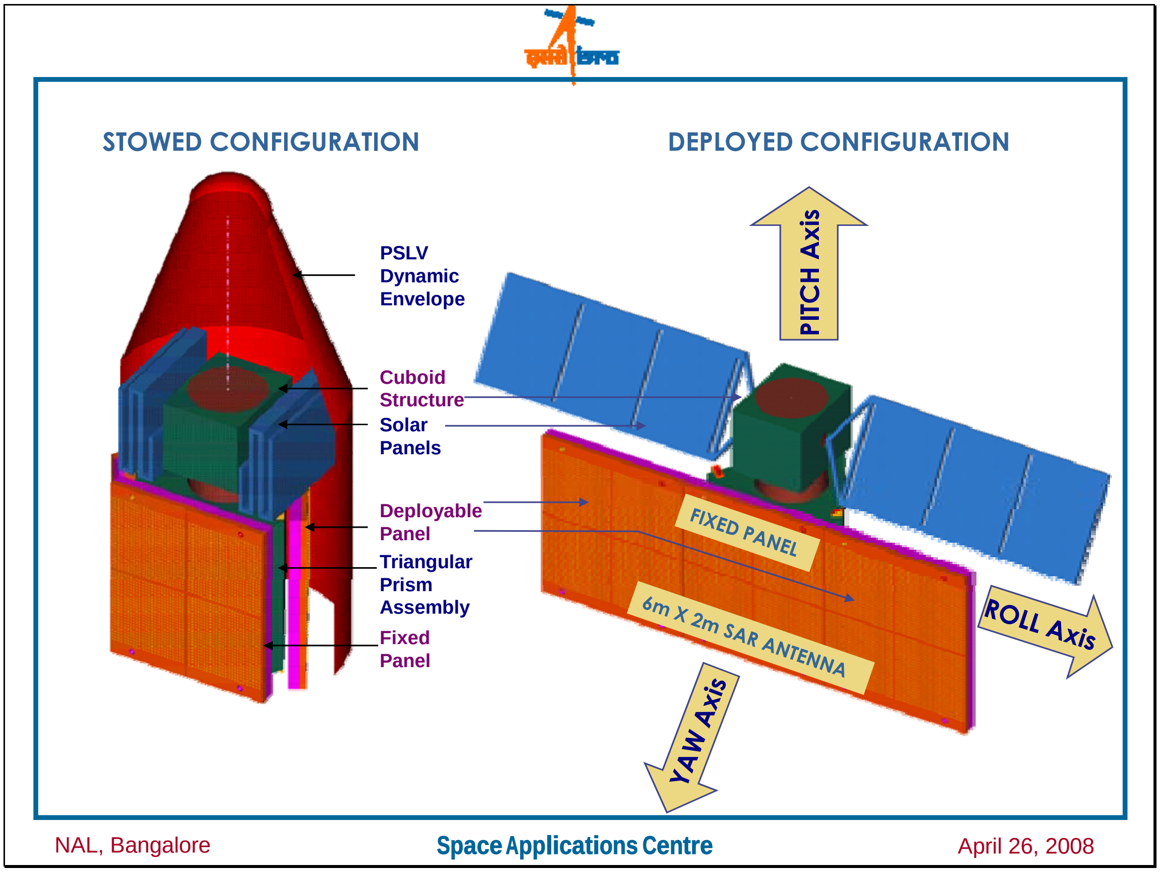
STRIPMAP MODE SPOTLIGHT MODE SCANSAR MODE

SINGLE/DUAL/QUAD POLARISATION IMAGING WITH 2-50 M RESOLUTION AND 10-240 KM SWATH

Stripmap, ScanSAR , Spotlight & Sliding Spotlight imaging modes.

RISAT SAR Capability

Coarse Resolution ScanSAR Mode (CRS)	50 m resolution over 240 Km swath with single/dual Polarization capability (Min σo -18 dB)
Medium Resolution ScanSAR Mode (MRS)	25 m resolution over 120 Km swath with single/dual polarisation capability (Min σo -18 dB)
Fine Resolution Stripmap Mode-2 (FRS-2)	9-12 m resolution over 30 Km swath with quad polarisation capability (Min σo -18 dB)
Fine Resolution Stripmap Mode-1 (FRS-1)	3-6 m resolution over 30 Km swath with single/dual polarisation capability (Min σo -17 dB)
High Resolution Spotlight Mode (HRS)	Better than 2 m resolution over 10 x 10 Km (10x100 km Experimental) spot with single/dual polarisation capability (Min σo -16 dB)



STOWED CONFIGURATION
DEPLOYED CONFIGURATION
PSLV Dynamic Envelope
Cuboid Structure
Solar Panels
Deployable Panel
Triangular Prism Assembly
Fixed Panel
PITCH Axis
FIXED PANEL
6m X 2m SAR ANTENNA
ROLL Axis
YAW Axis
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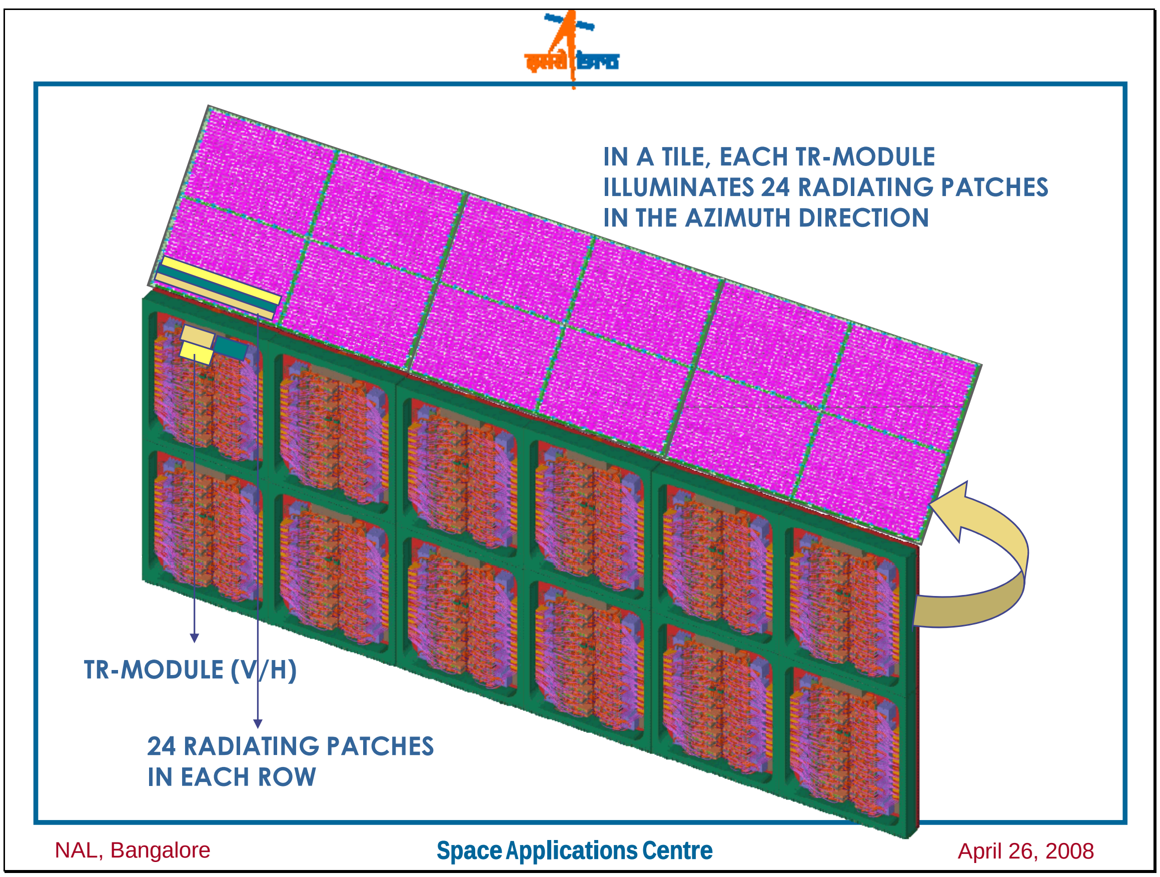

IN A TILE, EACH TR-MODULE
ILLUMINATES 24 RADIATING PATCHES
IN THE AZIMUTH DIRECTION
TR-MODULE (V/H)
24 RADIATING PATCHES
IN EACH ROW
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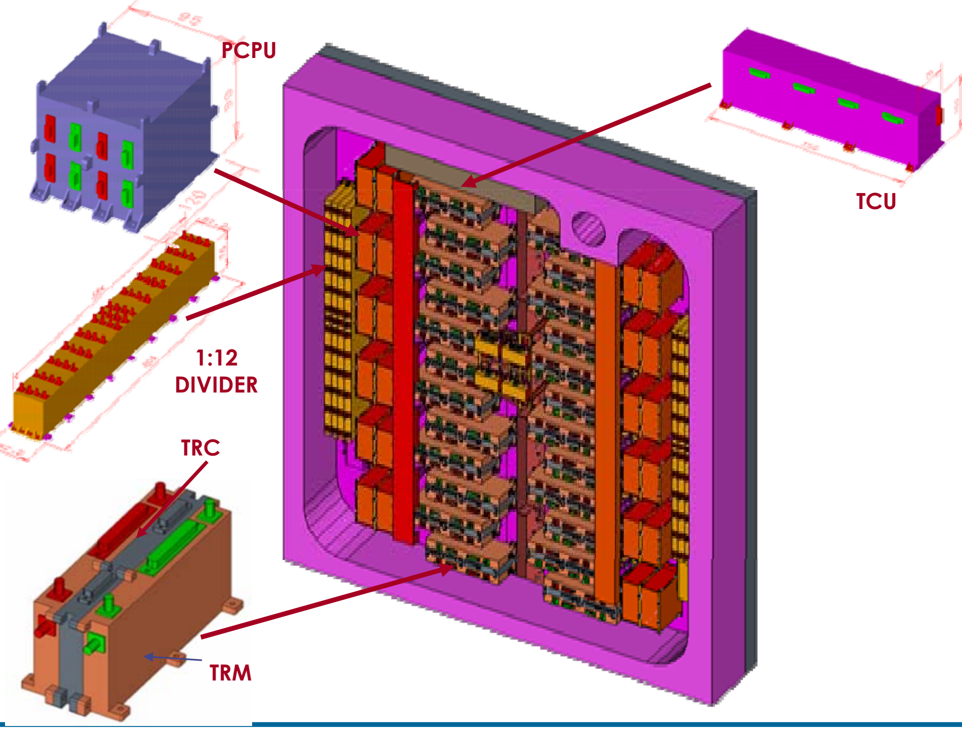

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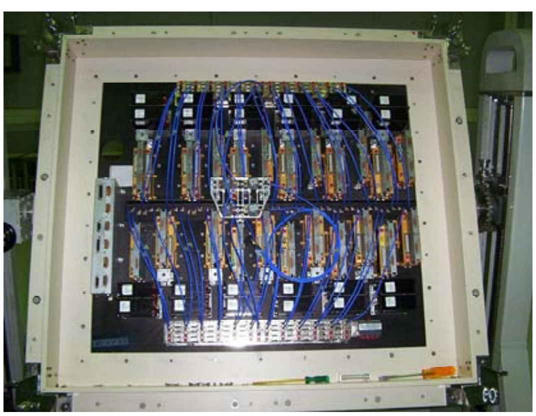

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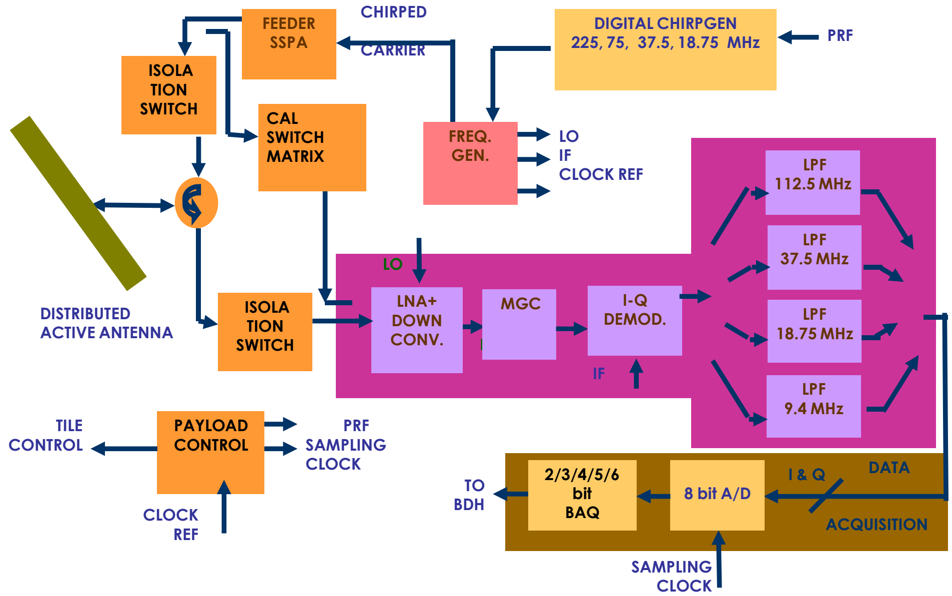
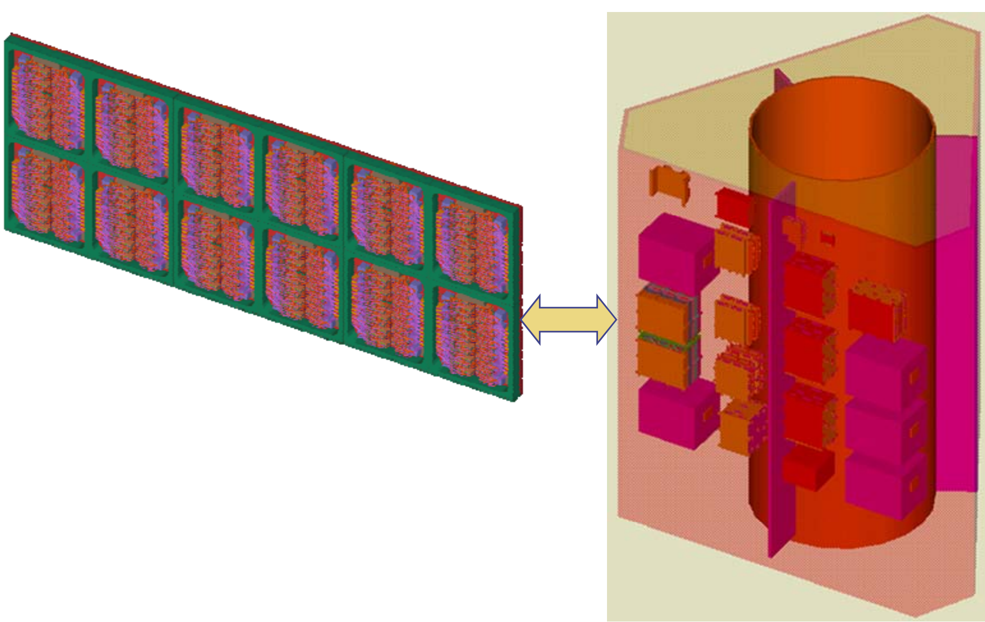
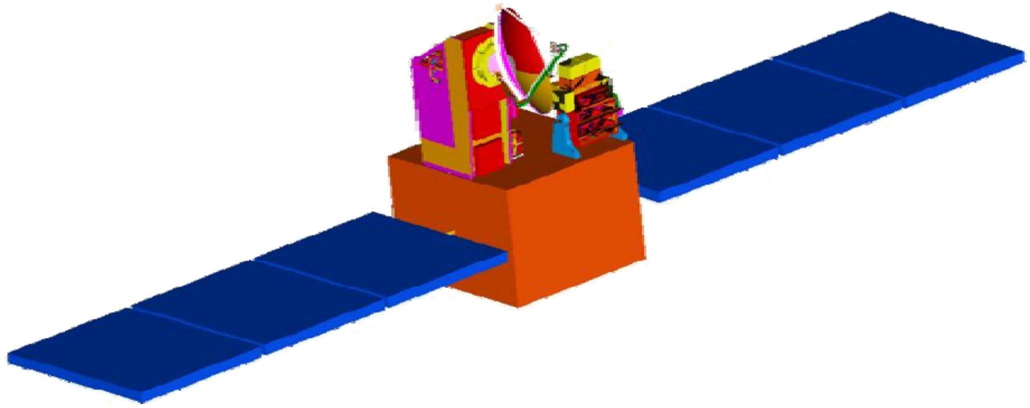


Configuration of RF and Baseband System

ACTIVE ANTENNA

RF AND BASEBAND SUBSYSTEMS (DECK PACKAGES)



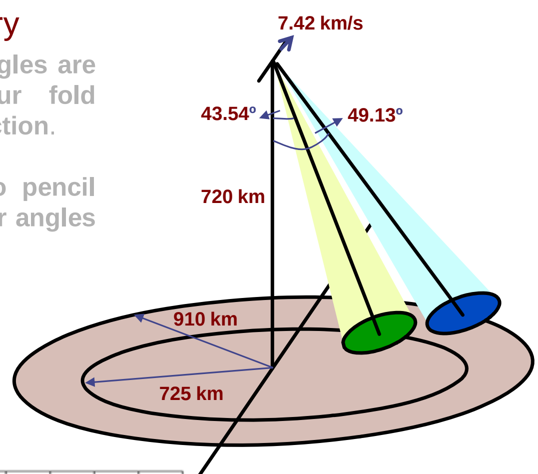


Ku-BAND SCATTEROMETER FOR OCEANSAT-II MISSION

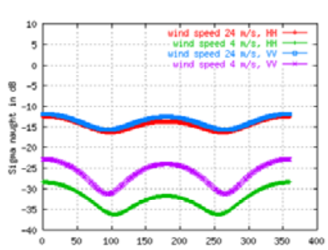
System Geometry

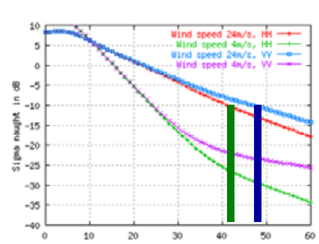
Measurements at multiple azimuth angles are required in order to remove four fold ambiguity in estimating the wind direction.

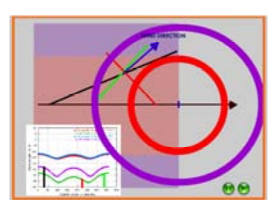
This is accomplished by having two pencil beams (inner and outer) with off nadir angles of 43.5° and 49.1°

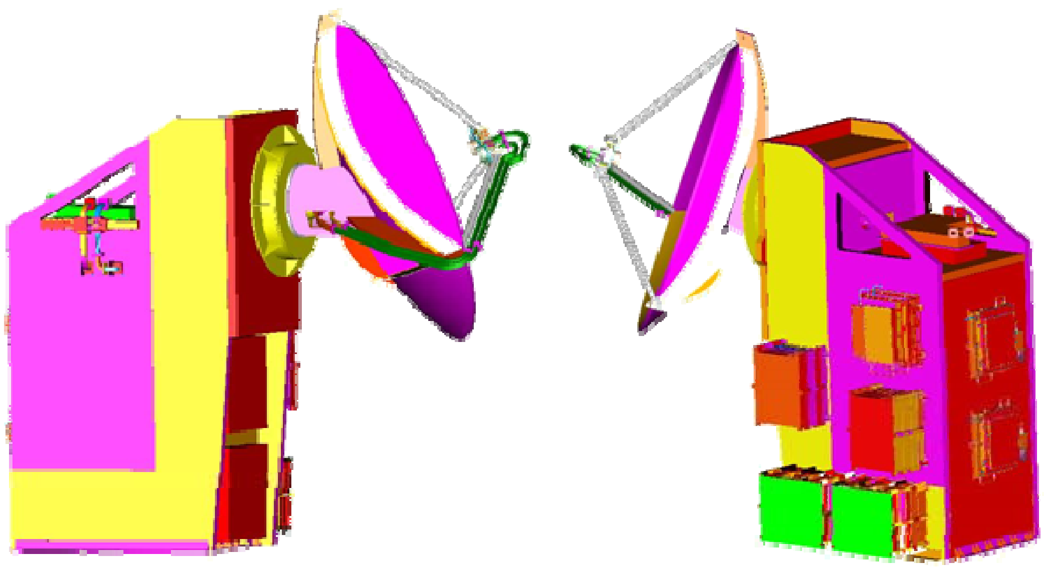


$\sigma_o = aU^x(1 + b\text{Cos}(\theta) + \text{Cos}(2\theta))$









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C-Band DMSAR FIRST FLOWN ON NOV 26 2005

Operating frequency	5350 MHz
Polarisation	HH, VV
Slant range resolution	<2 m, 3 m, 5 m, 10m
Azimuth resolution	<2 m, 3 m, 5 m, 10m
Swath coverage	6 Km, 25 km, 50 km, 75 km

PHOTOGRAPHS OF DMSAR SYSTEM

FREQUENCY: 5.35 GHz

SWATH: 75, 75, 50, 25, 6 KM

RESOLUTION: 30,10, 5,3,2 m

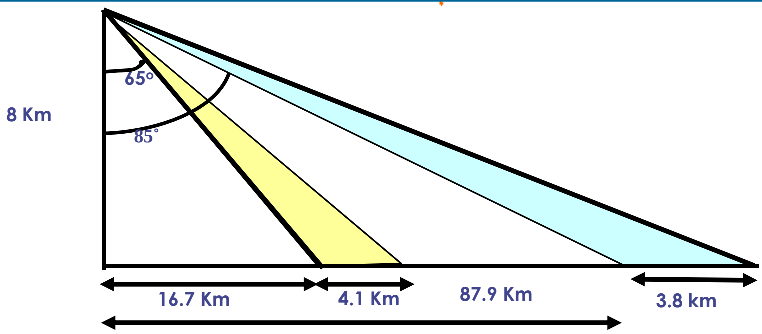

Fig. (a) Swath Geometry in <2m Resolution Mode

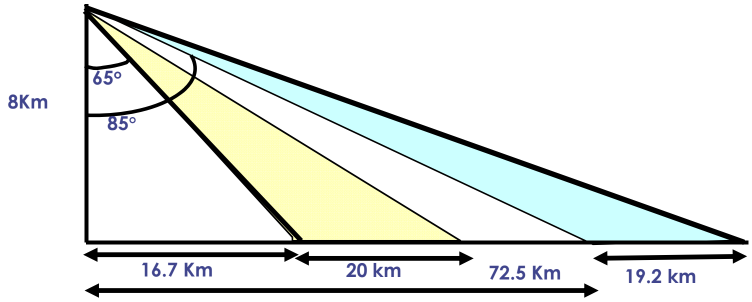

Fig. (b): Swath Geometry in 3m Resolution Mode

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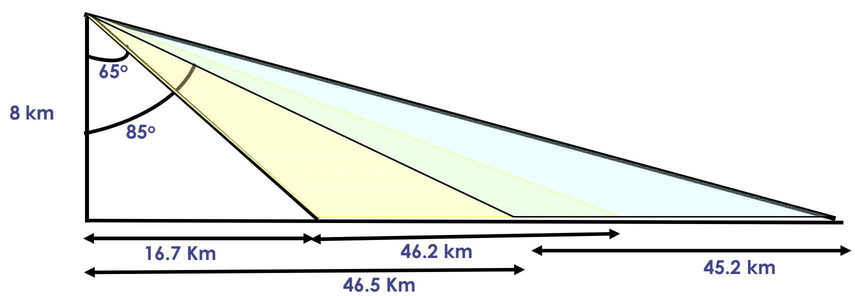

Fig. (c): Swath Geometry in 5m Resolution Mode

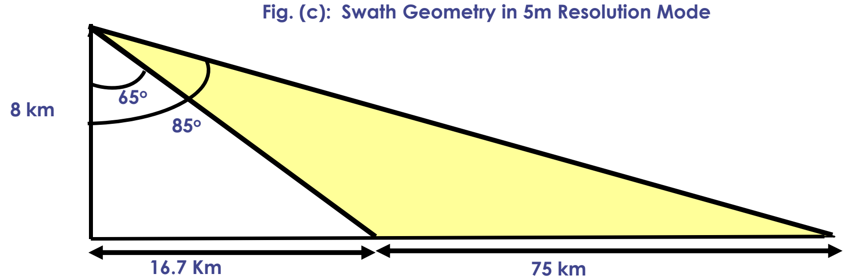

Fig. (d): Swath Geometry in 10m / 30m Resolution Mode

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Airborne Synthetic Aperture Radar for Disaster Management

Mission Parameters	
Frequency	5.35 GHz
Altitude	8 Kms
Resolution	10m/5m/3m/1m
Swath	6 – 75 Kms
Polarisation	HH / VV

Transreceiver Parameters	
Peak Power	8000 W
Average Power	72 W
Pulse Width	20 microsecs
Chirp Bandwidth	6.25 – 225 MHz
PRF	450 Hz

Data Handling Parameters	
Quantisation	8 I + 8 Q
Sampling Frequency	6.94 – 250 MHz
Data Rate	7.3 Msamples/sec

Major specifications of ISRO's Airborne and Spaceborne Microwave Radar Sensors

PARAMETER	ASAR	DM SAR	RISAT	SCATTEROMETER	ALTIMETER
MISSION					
Frequency of Operation	5.35 GHz	5.35 GHz	5.35 GHz	13.515625 GHz	13.48 GHz
Platform	Beech craft B-200 aircraft	Beech craft B-200 aircraft	IRS Spacecraft bus	IRS Spacecraft bus	IRS Spacecraft bus
Altitude	8 Kms	8 Kms	608.958 Kms	720 Kms	720 Kms
Platform Velocity	120 m/s. (Nominal)	120 m/s. (Nominal)	7.5 km/s	7.46 Km/s	7.46 Km/s
Off Nadir Look Angle	7° to 73	20° to 86°	9° to 47°	43.6°, 49.0°	Nadir Looking
Swath Coverage	25 Km	6.8 to 90 Kms	10 - 240 Kms	1450 - 1820 Kms	16 Kms
Resolution	6 m (Range) x 6m(Azimuth)	2-30 m (Range) 2-30 m.(Azimuth)	2 - 50 m. (Range) x 2- 50 m. (Azimuth)	2 m/s (wind speed) 20° rms (direction)	± 10 cms (Altitude) 0.5 m (SWH)

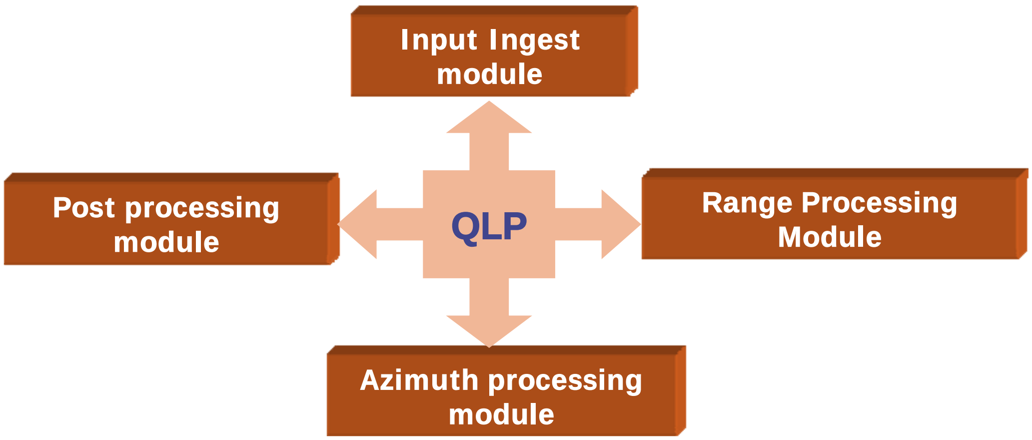
Major specifications of ISRO's Airborne and Spaceborne Microwave Radar Sensors (Cont'd)

PARAMETER	ASAR	DM SAR	RISAT	SCATTEROMETER	ALTIMETER
ANTENNA					
Antenna	Micro strip	Micro strip	Active Antenna	1 m parabola	1.2 m parabola
Gain	24.4 dB	26.5 dB	44.5dB	39 dB	42.5 dB
Beam width (Rng x Azi)	66 ° x 2.2 °	66 ° x 3 °	(1.6 °- 2.9 °) x 0.54 °	1.67 ° x 1.47 °	1.23 °
TRANS – RECEIVER					
IF Frequency	123.256 MHz	850 MHz	850 MHz	15.625 MHz	100 MHz
Transmit Power	2 Kw. (P) 20 W (A)	8 Kw (P) 72 W (A)	2.9 Kw (P) 213 W (A)	100 W (P) 28 W (A)	4 W (P)
Transmit Pulsewidth	20 μsec	20 μsec	20 μsec	20 μsec	20 μsec
PRF	500 Hz. (Nominal)	450 Hz (Nominal)	2800 – 3700 Hz (Nominal)	200 Hz	1325 Hz
RF Bandwidth	27.5 MHz	225 MHz	225 MHz	1.4 MHz	320 MHz

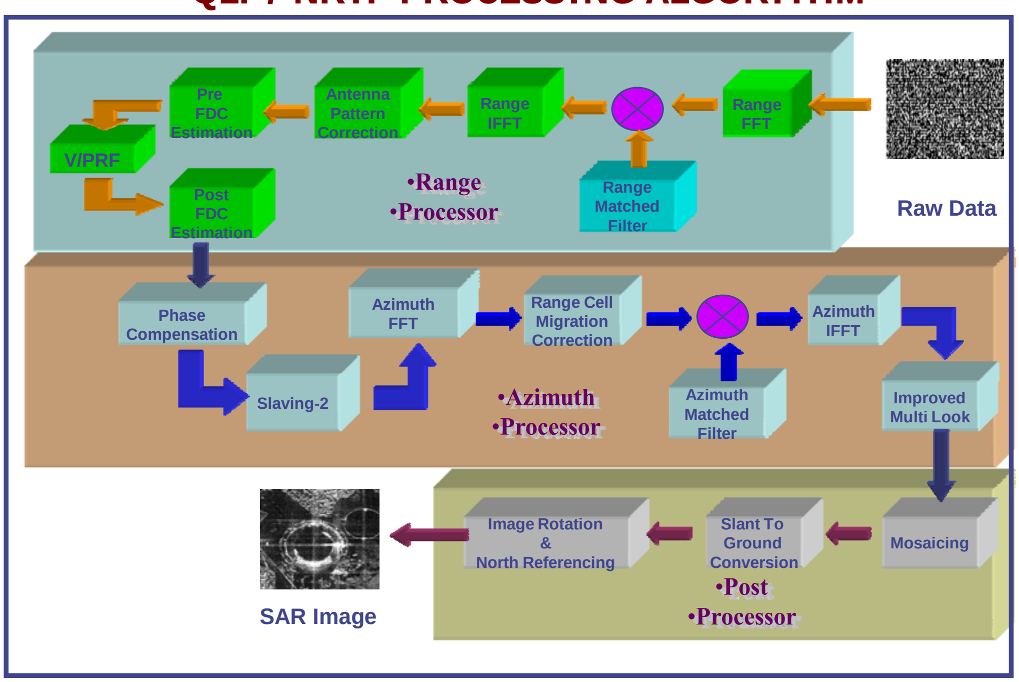
Major specifications of ISRO's Airborne and Spaceborne Microwave Radar Sensors (Cont'd)

PARAMETER	ASAR	DM SAR	RISAT	SCATTEROMETER	ALTIMETER
DIGITAL					
Quantization	6 bits I 6 bits Q	8 bits I 8 bits Q	2-6 BAQ bits I 2-6 BAQ bit Q	8 bits I + 8 bits Q	5 bits I + 5 bits Q
Sampling Window	166.2 μsec.	63 - 762 μsec.	55 - 181 μsec.	1.835 msec.	102.4 μsec.
Sampling Rate	30.814 MHz	6.94 - 250 MHz	20.8 - 250 MHz	2.232 MHz	625 KHz
Data rate	37 Mbps (raw data) 150 Kbps (proc.)	118 Mbps. (raw data) 30 Mbps. (proc.)	44-1500 Mbps. (6 BAQ raw)	20 Mbps. (raw) 400 Kbps (processed)	30 Kbps (processed)

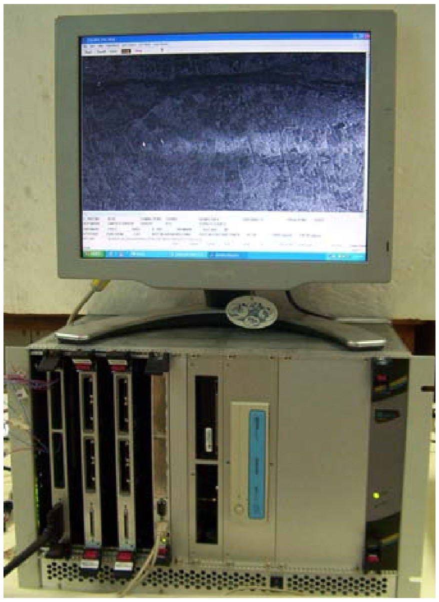
SAR Processor Functional Modules



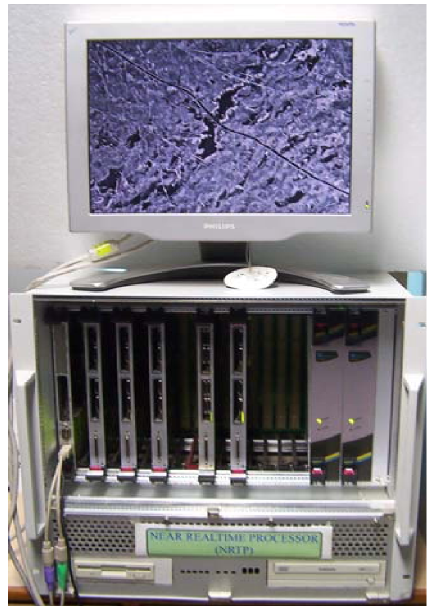
QLP/ NRTP PROCESSING ALGORITHM

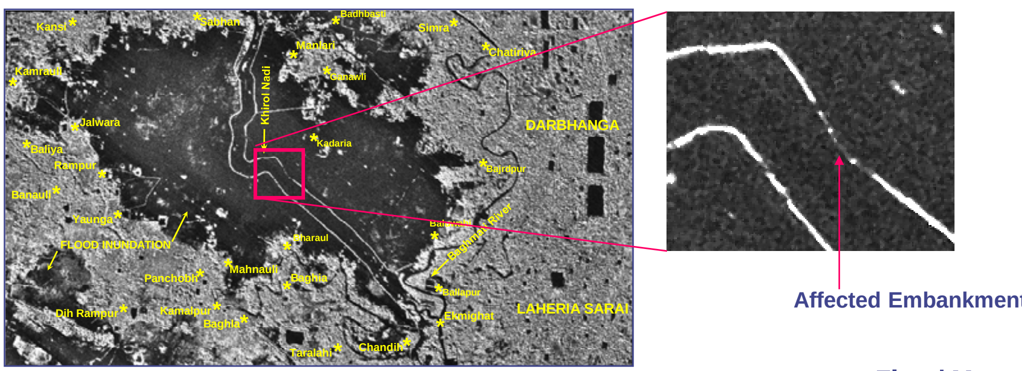


QLP SYSTEM FOR DMSAR



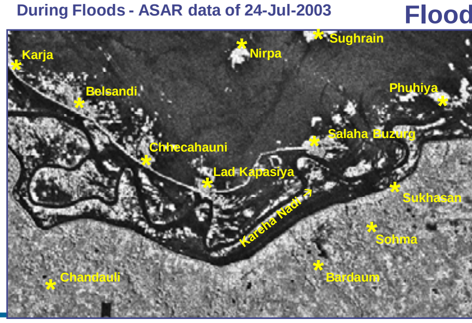
NRTP SYSTEM FOR DMSAR





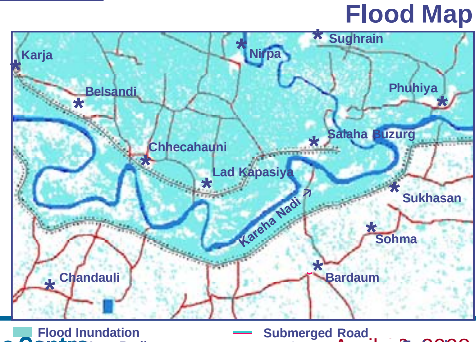
During Floods - ASAR data of 24-Jul-2003

Flood

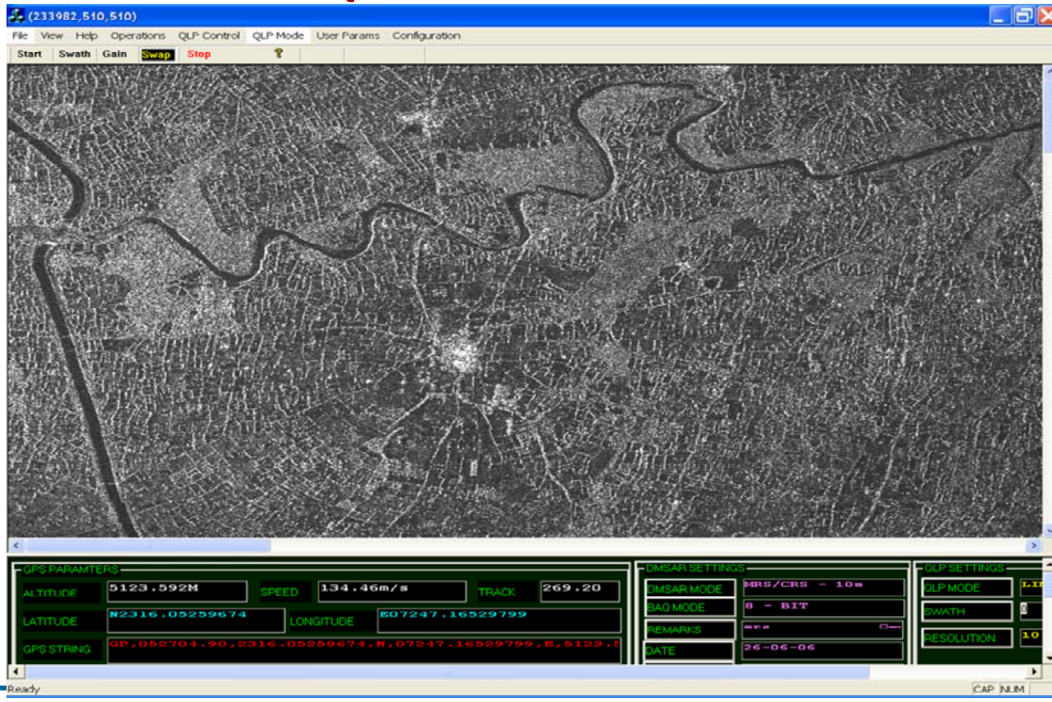


During Floods - AirSAR data of 24-Jul-2003

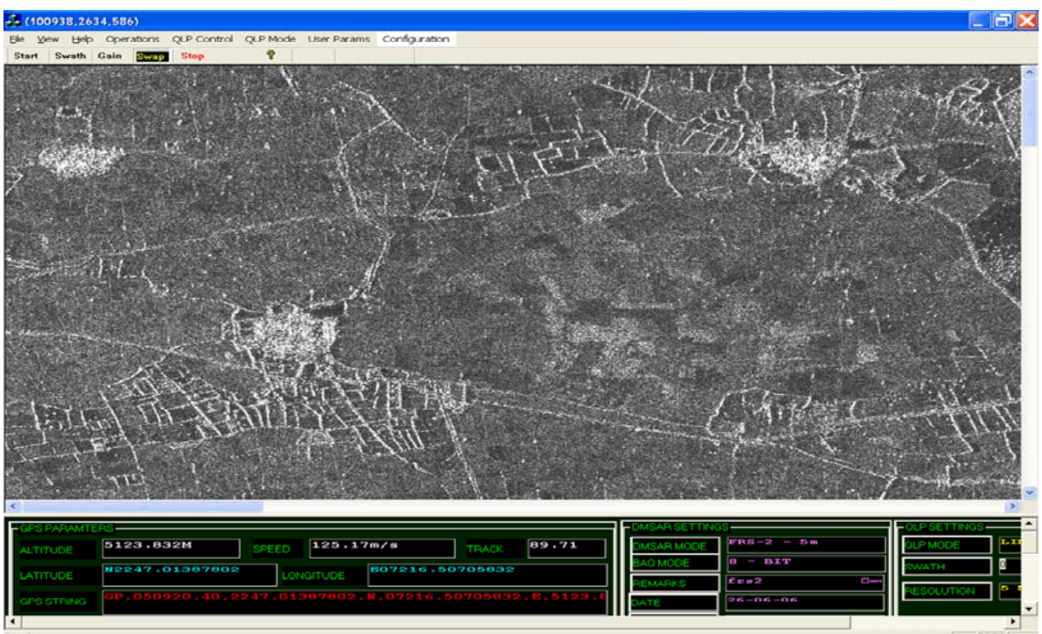
Flood Map



QLP IMAGE-1 : 10m Resolution



QLP IMAGE-2 : 5m Resolution



High Res. MODE **DMSAR IMAGE**

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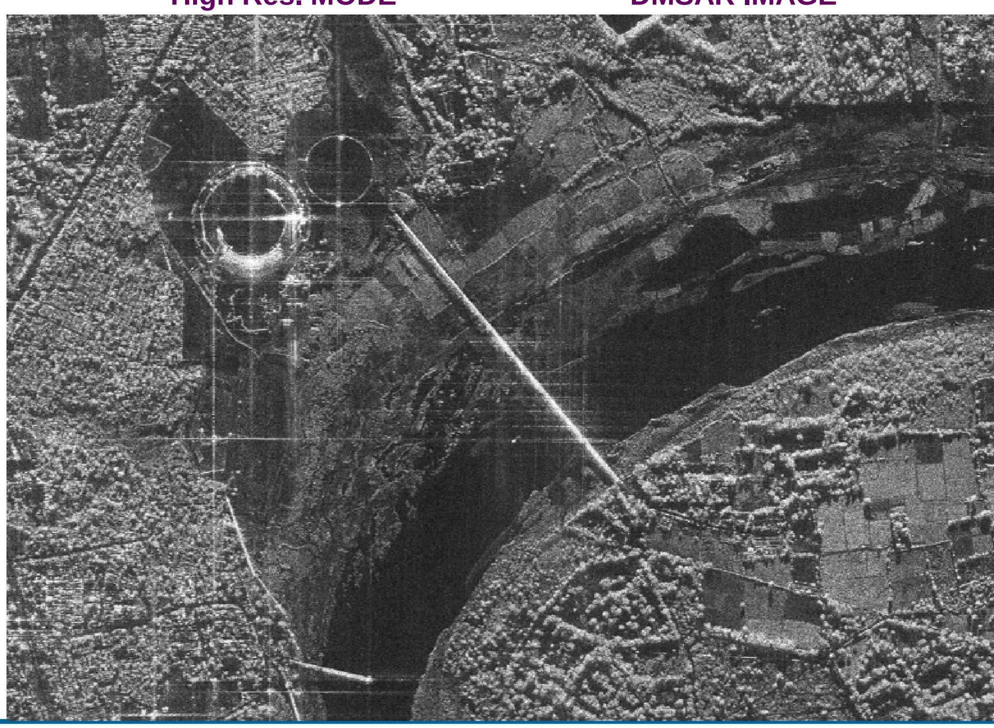
High Res. MODE **DMSAR IMAGE**



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3 Meter MODE DMSAR IMAGE

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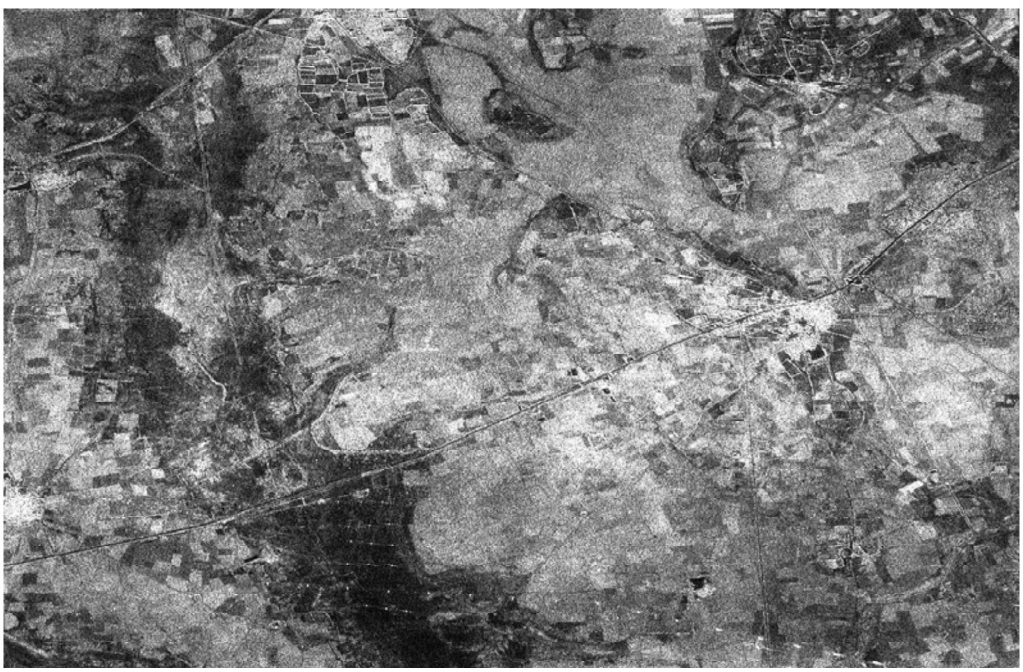
10 Meter RESOLUTION CALIBRATION SITE



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10 Meter Resolution Point Targets

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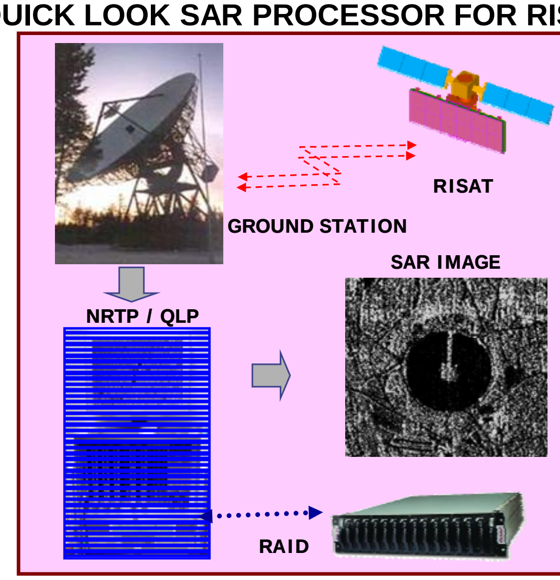
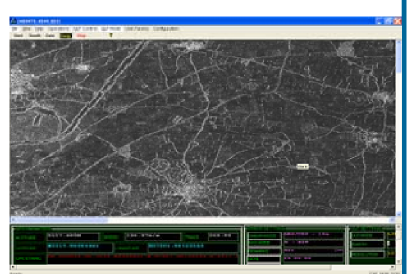
GROUND SEGMENT CHALLENGES : REAL TIME SAR PROCESSING AND PRODUCT DISSEMINATION

QUICK LOOK SAR PROCESSOR FOR RISAT



SAR IMAGE & OTHER VALUE-ADDED PRODUCTS



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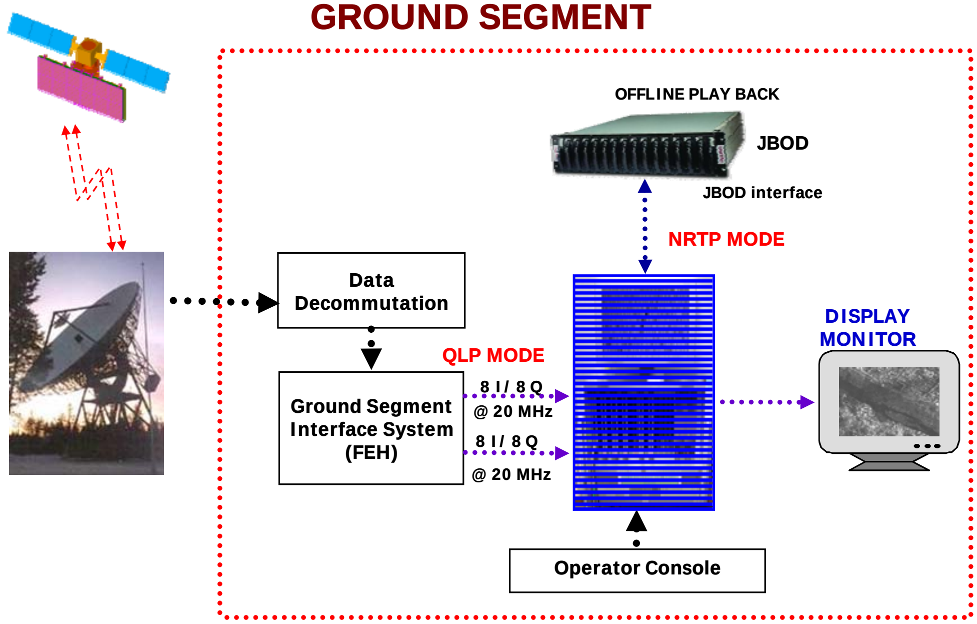
QLP / NRTP CONFIGURATION FOR RISAT GROUND SEGMENT



CONCLUSIONS

- Microwave remote sensing is very prospective from the space research and applications point of view.
- ISRO on the threshold of evolving a full-fledged operational microwave remote sensing programme.
- SAR could be an important onboard imaging sensor candidate for Providing Enhanced and Synthetic Vision for NAL's Transport Aircraft
- For further Details Contact :
  - Director, SAC
  - Shri S.S. Rana, Deputy Director-MRSA/SAC

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THANKS

Speaker Profile

Nilesh M. Desai was born in 1964 at Gujarat, India. He holds B.E. degree in Electronics and Communication Engineering (1986) and is a top ranker and gold-medalist of 1986 batch from L.D.College of Engineering, Gujarat University, Ahmedabad, India. He joined Space Applications Centre (SAC), Indian Space Research Organisation (ISRO), Ahmedabad, in 1986. He carries with him a rich experience of 22 years, working as Scientist/Engineer in different capacities and has contributed extensively towards ISRO's various airborne and spaceborne Radar Projects like ASAR, DMSAR, RISAT-1, Oceansat-I, Oceansat-II, Megha-Tropqiues etc.. Presently, he is heading Microwave Sensors Data Acquisition and Processor Division (MSDPD) of Microwave Sensors Digital Electronics Group (MSDG) of SAC/ISRO, Ahmedabad. He has worked extensively in the design and development of real time data acquisition and digital signal processing systems for ISRO's radar projects. He is also holding the responsibilities as Deputy Project Director – SAR Digital Systems for ISRO's Radar Imaging Satellite-1 (RISAT-1) and Airborne SAR for Disaster Management (DMSAR) missions. He has been the main author or co-author of more than 40 technical papers presented at various national and international conferences in India and outside India. He has also contributed significantly in more than 60 internal technical reports of SAC/ISRO. Since last fifteen years, he has also been working as an expert and project guide in ISRO for various Post-graduate, Undergraduate and Diploma Engineering students as well as ISRO's new recruit Engineers (under ISRO Induction Training Programme), carrying out their project thesis/ training at SAC/ISRO. He has also represented ISRO as a member of ISRO delegations at various international seminars and conferences in countries like Germany, Singapore, Israel, France etc. His fields of interest and research include Data Acquisition and Digital Signal Processing for radar data, DSP and Microprocessor architectures, VLSI digital design and FPGA / ASIC hardware design, embedded systems and software quality assurance.

GPS Aided Navigation system for GNC of Space Capsule Recovery Experiment (SRE) and Launch Vehicles: Development & Flight Performance

Dr. P.P.Mohanlal

ISRO Inertial Systems Unit, Trivandrum, India.

The Space Capsule Recovery Experiment (SRE) is the first Indian experiment in which a space vehicle is de-orbited from a low earth orbit and recovered from the Indian coastal waters on 22nd of January 2007. The main objective of SRE is to provide a micro-gravity platform for scientific experiments, demonstrate a host of new technologies for safe reentry of future manned modules into the earth's atmosphere and safe landing. One of the major challenges in SRE is the Guidance, Navigation and Control (GNC) system. This paper presents the details of the precision hybrid navigation system of SRE, comprising of IMU, fine sun sensor, magnetometer, satellite navigation receiver and robust navigation integration filter designed, developed and successfully used to achieve the mission. As per the mission plan, the capsule is de-orbited under the closed loop GNC to achieve the re-entry pillbox at 100 km altitude very precisely. Below 100 Km, the aerodynamically stable capsule follows ballistic flight, terminal velocity reduction by parachutes for safe splash down within the specified impact zone for recovery. Further, this paper presents the major design aspects and the flight performance of the Hybrid Navigation System.

The 550 Kg Space Capsule of SRE is launched into 625 Km circular polar orbit on 10th January 2007 by the PSLV-C7 vehicle, the seventh operational flight of Polar Satellite Launch Vehicle (PSLV) of Indian Space Research Organization (ISRO) from the Shriharikota launch complex. On the 10th day the first de-boost is carried out under closed-loop GNC to transfer the capsule to an elliptical orbit to have daily opportunity for final de-boost and recovery. On the 12th day the final de-boost is done for reentry and splash down in the Indian waters off the coast of Shriharikota. Figure 1 shows the overall mission profile.

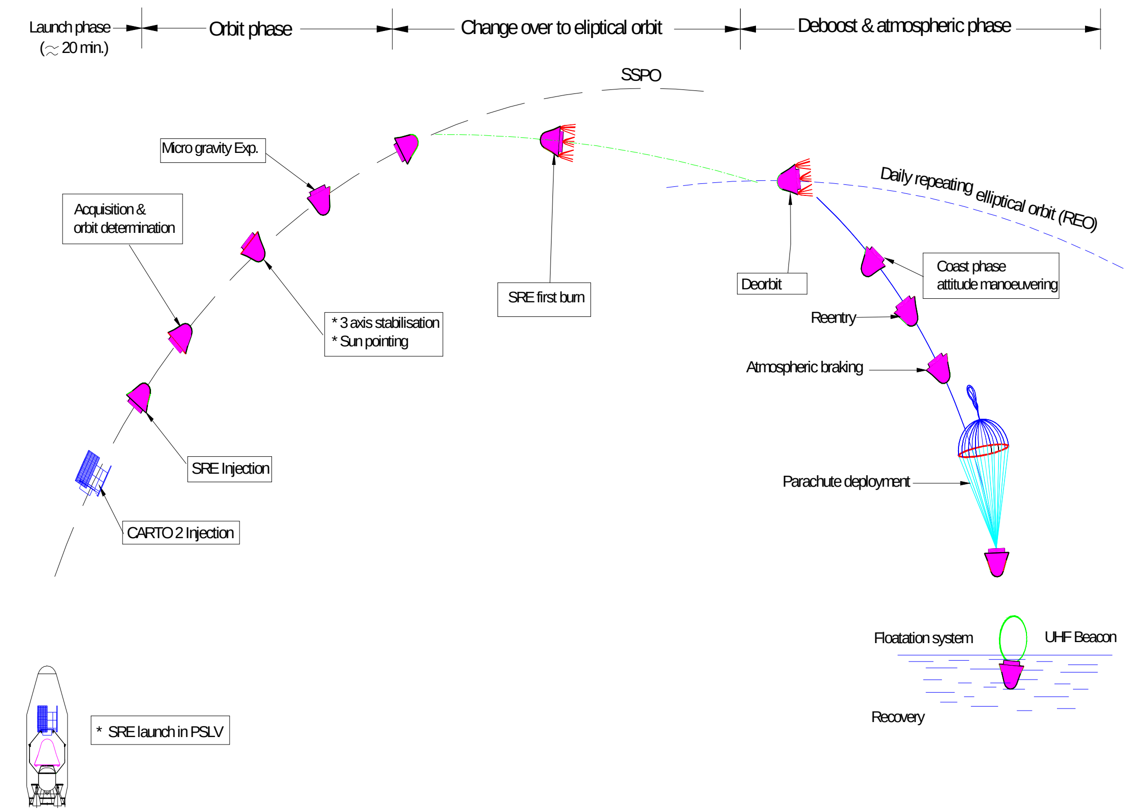


Figure1: Overall Mission Profile

The capsule has to be navigated to enter earth's sensible atmosphere (100 Km) with a precise position, velocity, Flight Path Angle (FPA) and angle of attack such that the reentry thermal loads are with in design limits. The state vector at the entry pillbox at 100 Km altitude has to be very accurate to achieve the desired impact point accuracy. This imposes major accuracy constraint on the navigation system design.

Even though the autonomous Inertial Navigation System (INS) has very good accuracy in terms of gyros and accelerometers, the uncertainties in the initial state vector and attitude for de-boost phase is very critical and hence Hybrid navigation (INS aided with GNSS) could only meet the mission accuracy. For this purpose, GNSS aided navigation algorithm based on optimal Kalman Filter was designed and developed.

Excellent navigation accuracy has been achieved using the Hybrid navigation in the orbit transfer and final de-boost phases. In the orbit transfer phase, perigee accuracy of 15m is achieved.

In the final de-boost, the reentry pillbox has been achieved very accurately and the splash down point range error is only 4 Km from the planned location due to GNC. The details of the design, validation and flight performance are presented in part I.

The development of GPS aided INS for launch vehicle navigation poses additional challenges namely high acceleration, jerk and augmented INS error model to take care of high dynamic conditions.

The receiver should be able to track satellites under high acceleration and jerk during the ascend phase. For this purpose, a special receiver was designed and qualified under simulated dynamics using a GPS RF simulator. The same simulator is used to ensure satellite visibility by incorporating the measured 3D antenna pattern also in the RF simulation.

The aided navigation system was flight tested onboard PSLV C8 in 2007 and excellent navigation performance obtained in addition to accurate real time orbit determination. The details are presented in part II of the presentation.

GPS Aided Inertial Navigation System for SRE and Launch Vehicle

26th April 2008

Dr.P.P.Mohanlal

Launch Vehicle Inertial Systems
ISRO Inertial Systems Unit

Part I

- **GPS Aided Inertial Navigation System for Space Capsule Recovery Experiment**

Part II

- **GPS Aided Inertial Navigation System for Launch Vehicle Navigation**

SRE Project

Historic re entry

22nd January 2007, 9.47 a.m., ISRO's SRE capsule was recovered successfully.

India's historic entry to the elite club of countries having reentry technology

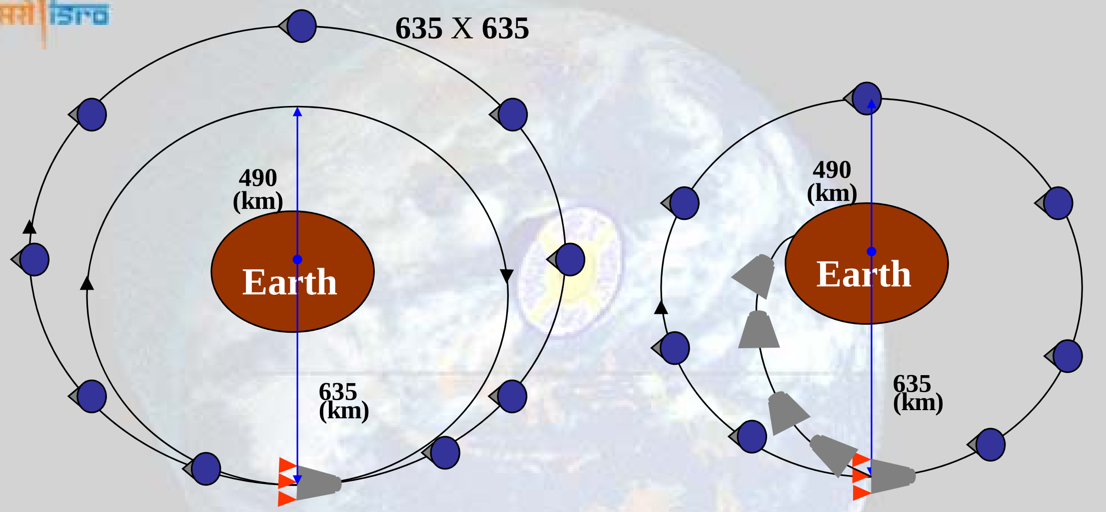
SRE laid the foundation for

- Reusable launch vehicles
- Manned missions
- Microgravity processing
- Sample return missions.

SRE PROJECT

- **Develop and demonstrate technology elements for recovery of orbiting space capsule (560kg),**
- **Launch aboard PSLV-C7,along with CARTOSAT-II**
- **Provide platform for microgravity experiments**
- **Recovery in Sea about 140 km (within +/- 50 km), East of SHAR**
- **Nominal impact point:** Latitude :13.16 deg & Longitude : 81.41 deg

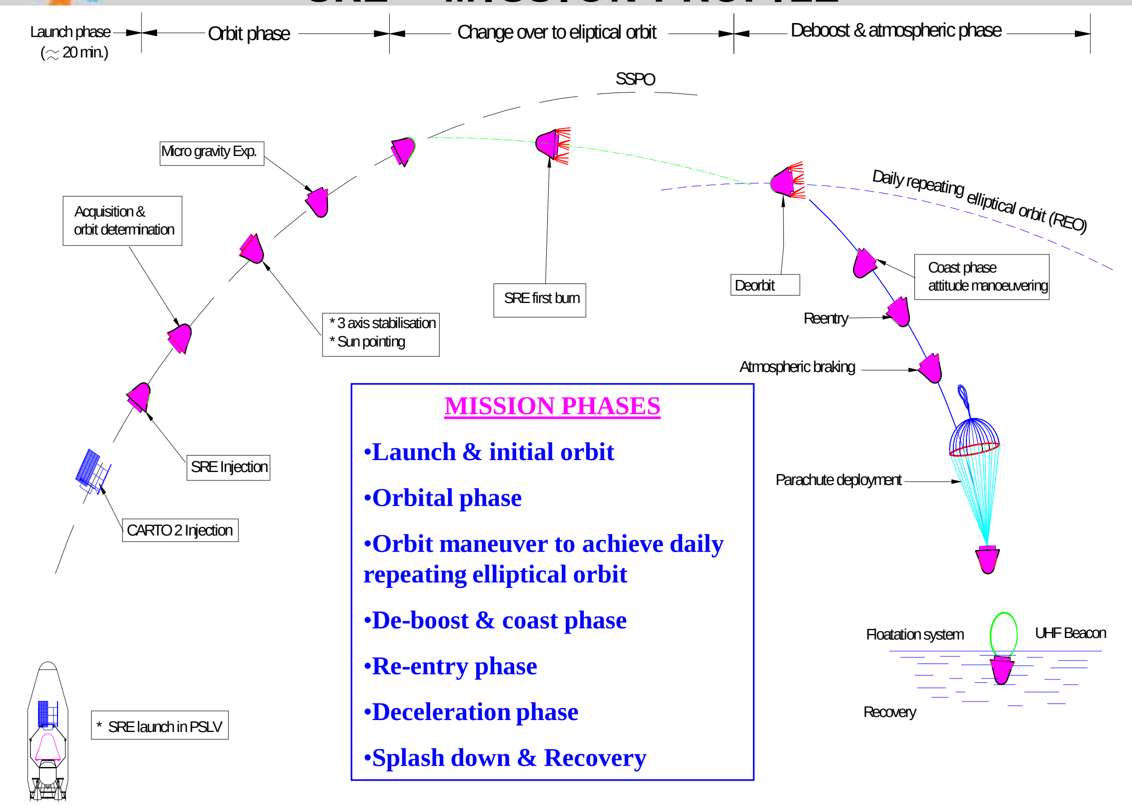
MISSION - ORBIT & DEBOOST



Using 22 N thrusters (8 nos.):

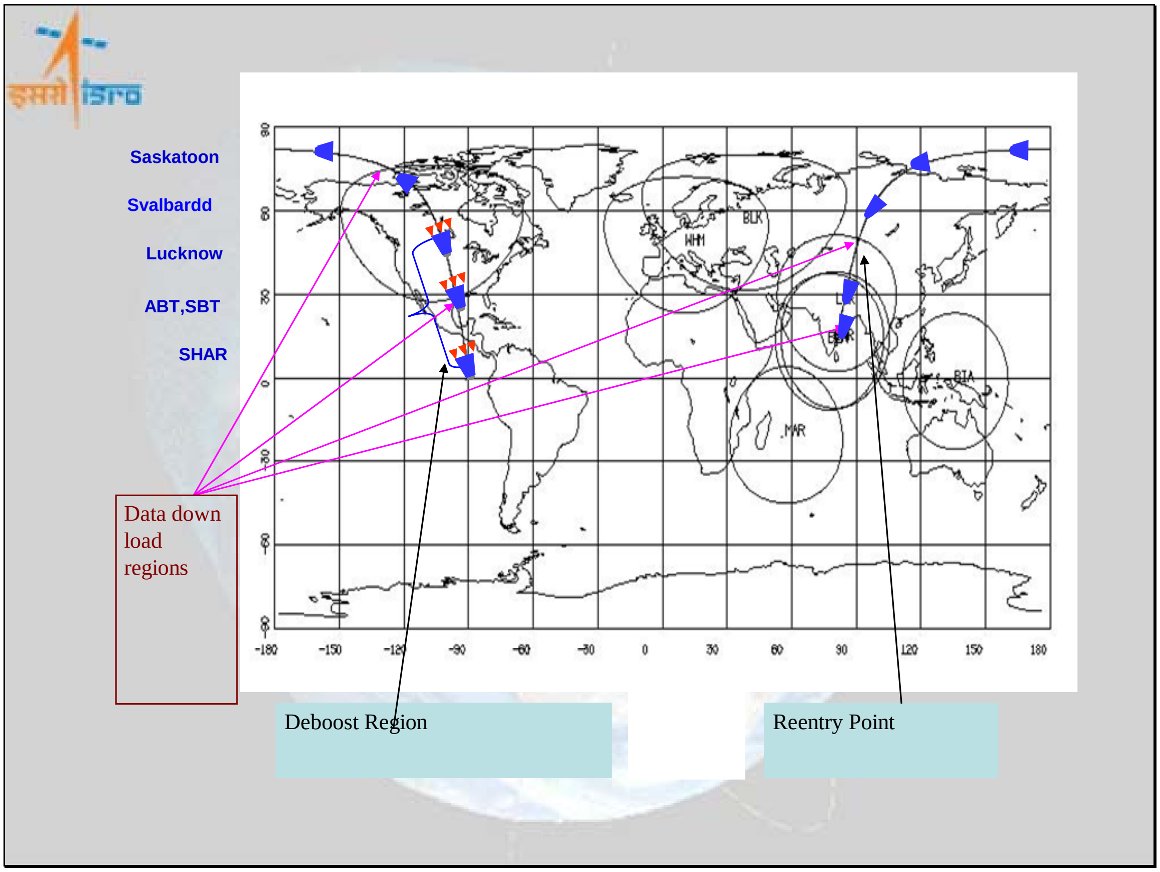
- Re-orientation maneuvers for acquisitions, on-orbit control
- Ground track control to ensure the track
- Orbit maneuver burn, using CLG, to obtain REO and the desired argument of perigee for de-boost
- De-boost burn to obtain the required target parameters at 100 km.

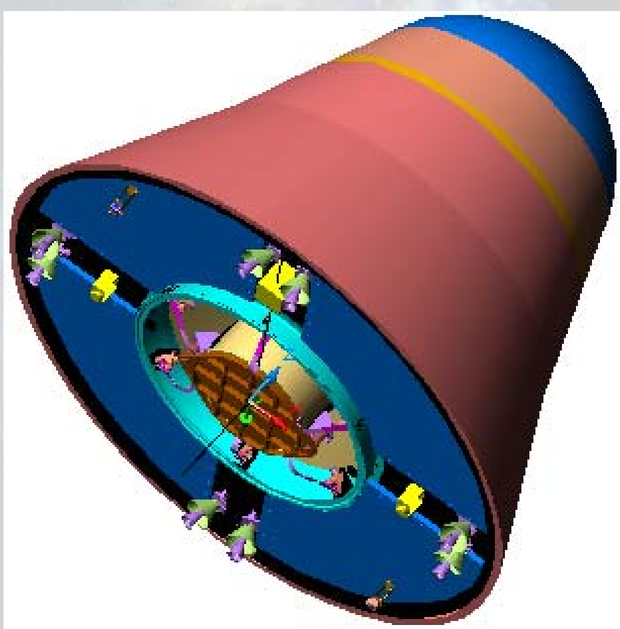
SRE – MISSION PROFILE

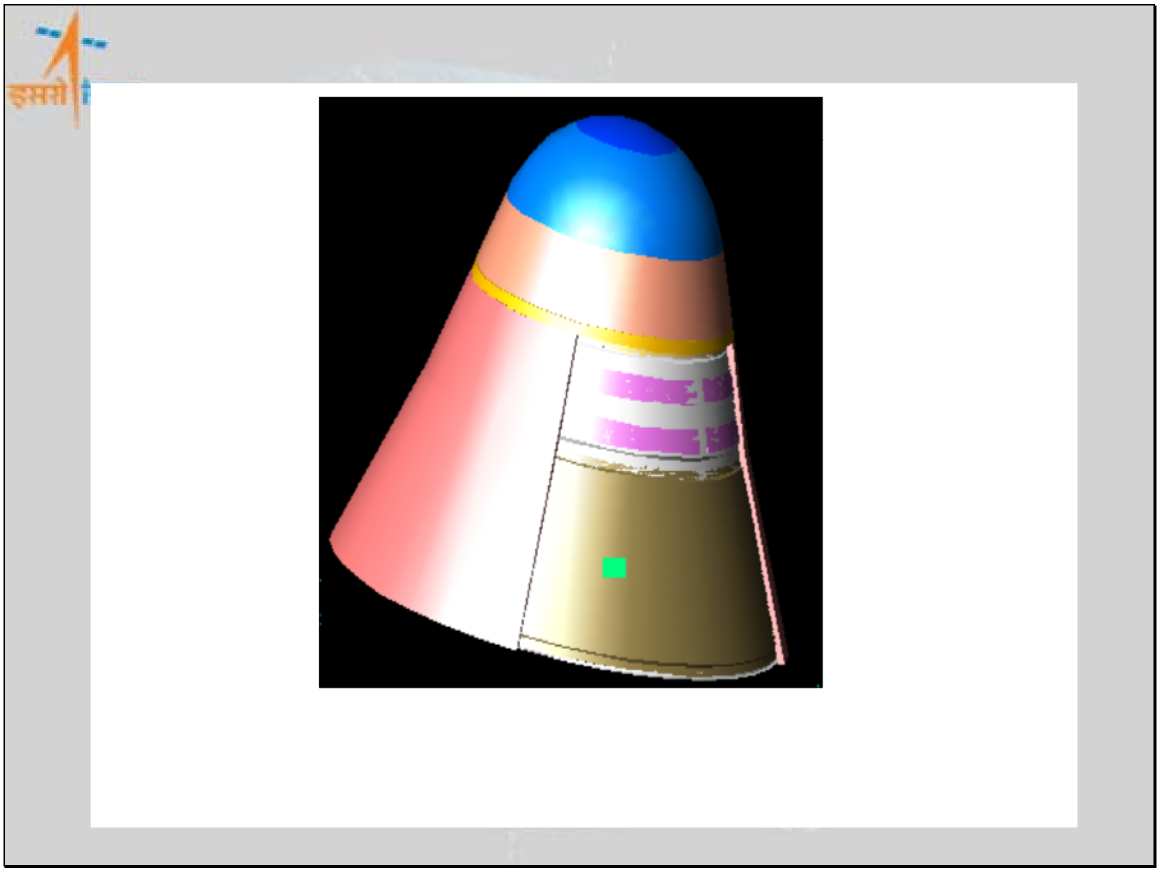


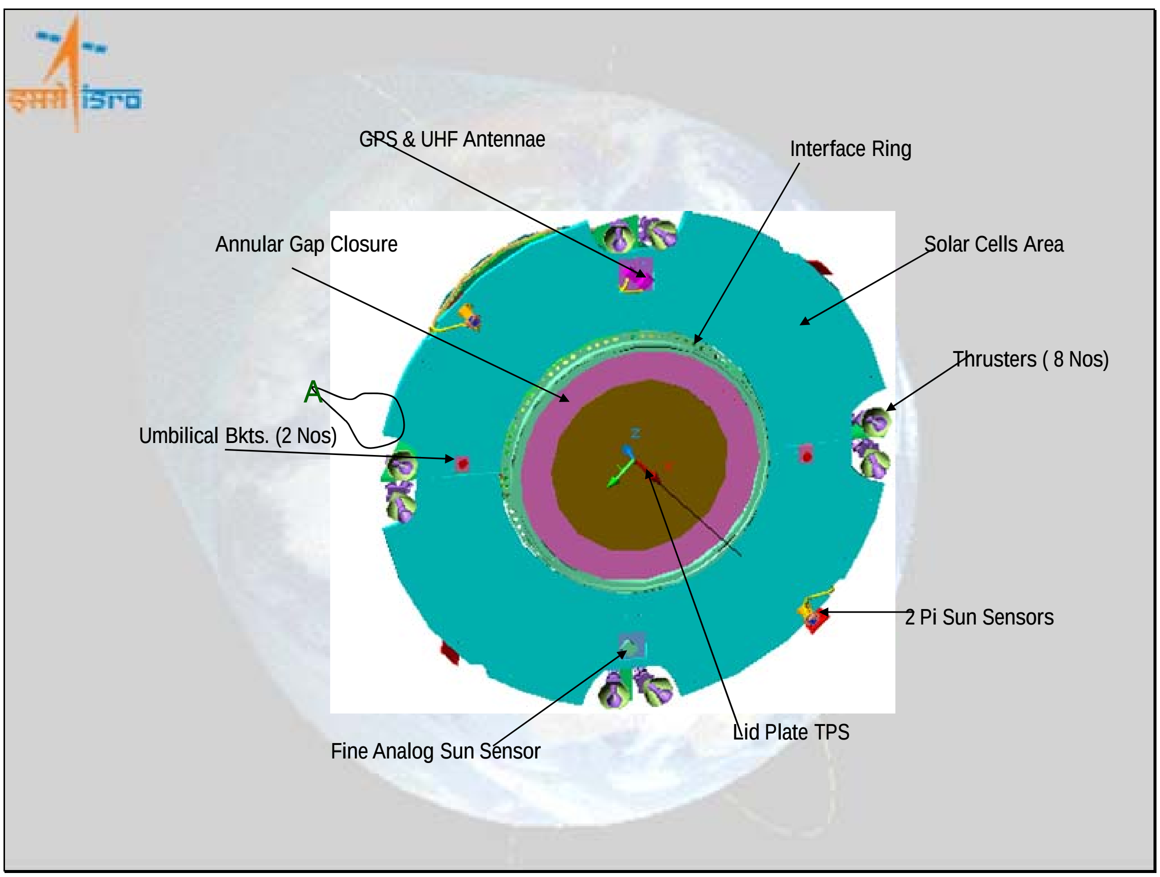
MISSION PHASES

- Launch & initial orbit
- Orbital phase
- Orbit maneuver to achieve daily repeating elliptical orbit
- De-boost & coast phase
- Re-entry phase
- Deceleration phase
- Splash down & Recovery


Saskatoon
Svalbardd
Lucknow
ABT,SBT
SHAR
Data down load regions
Deboost Region
Reentry Point
BLK
HHM
MAR
BIA
-180 -150 -120 -90 -60 -30 0 30 60 90 120 150 180



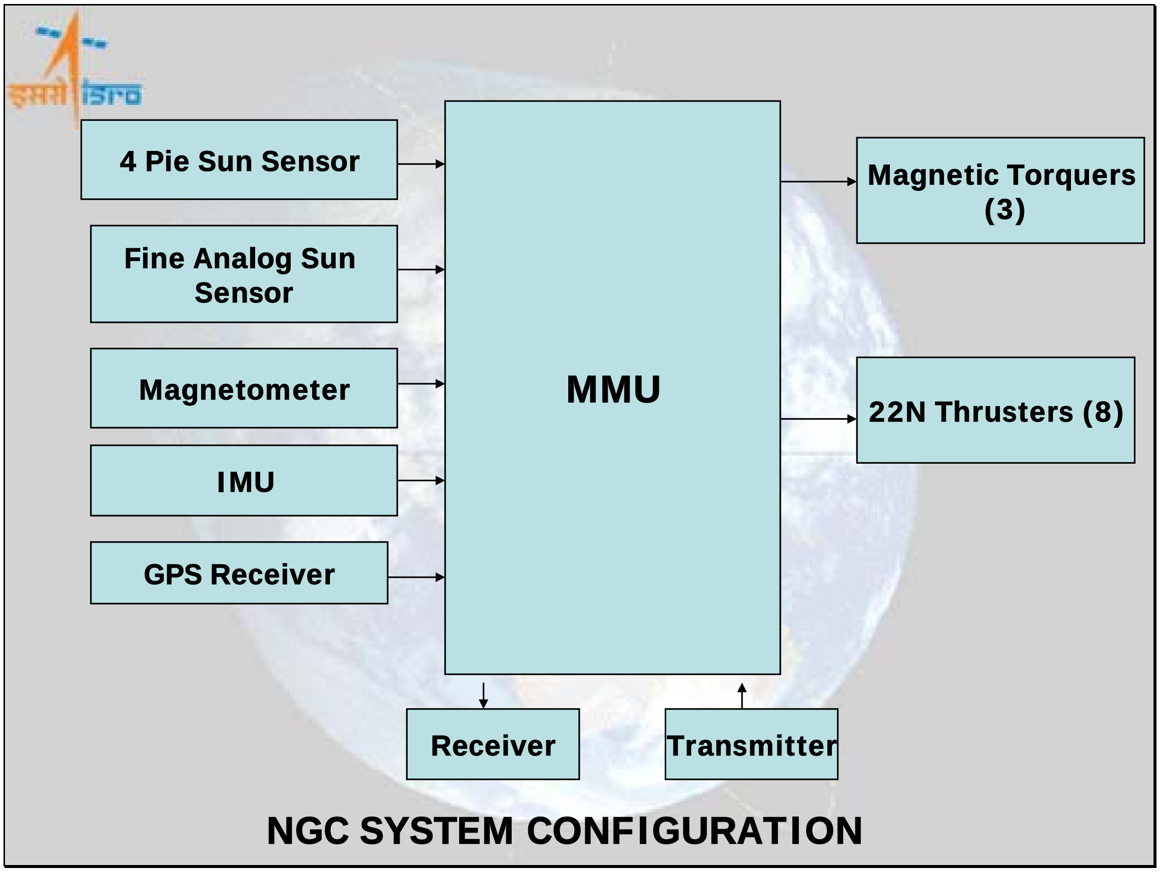


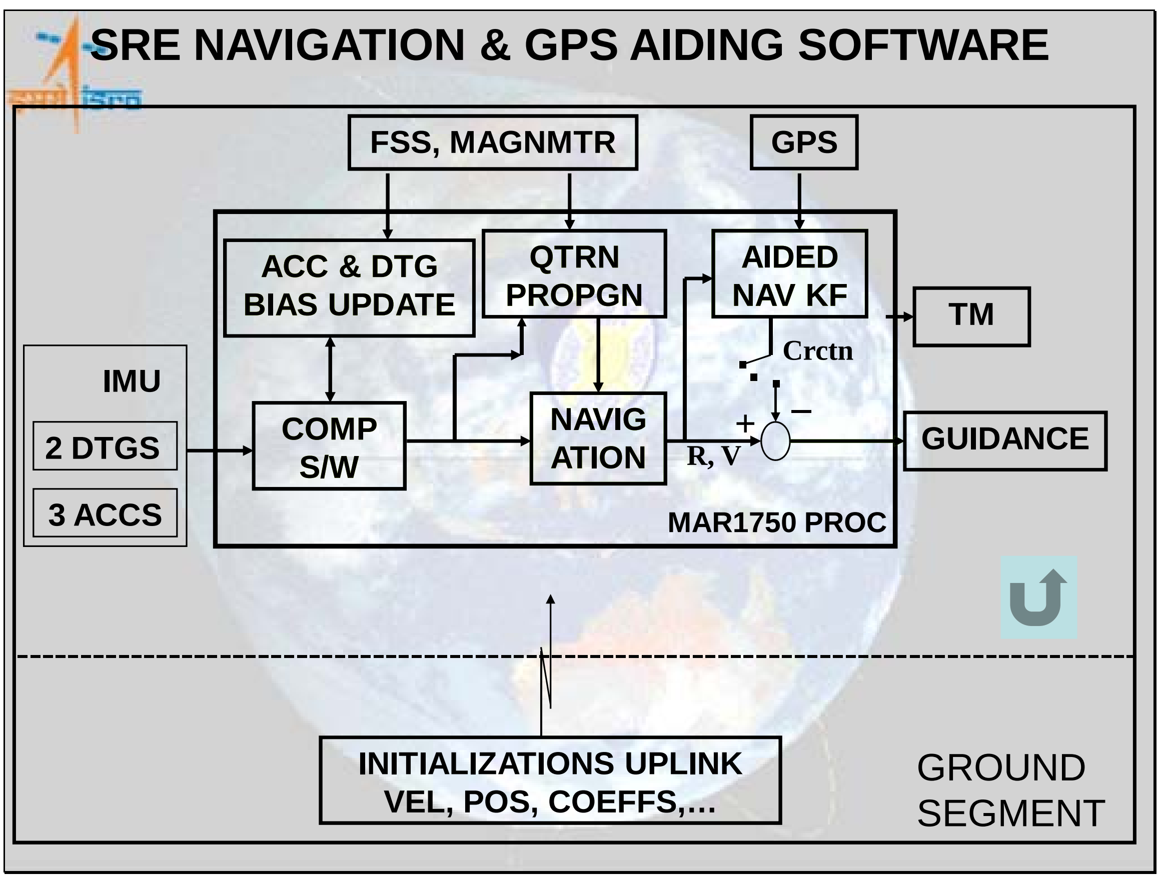

GPS & UHF Antennae
Interface Ring
Annular Gap Closure
Solar Cells Area
Thrusters (8 Nos)
A
Umbilical Bkts. (2 Nos)
2 Pi Sun Sensors
Lid Plate TPS
Fine Analog Sun Sensor

- Overall configuration
- Salient Features and Sequence of events
- **Acc bias update and Gyro update**
- **INS processing**
- **GPS Aiding and Design Validation**
- **Onboard software verification and validation**

Aided Navigation

- Aiding Scheme and Design features
- GPS & INS data synchronization : Latency correction
- Selection of Kalman filter states
- Kalman filter equations
- Model validation
- Process noise covariance estimation (Q)
- Scheduling of KF GAINS


4 Pie Sun Sensor
Fine Analog Sun Sensor
Magnetometer
IMU
GPS Receiver
MMU
Magnetic Torquers (3)
22N Thrusters (8)
Receiver
Transmitter
NGC SYSTEM CONFIGURATION


SRE NAVIGATION & GPS AIDING SOFTWARE
FSS, MAGNMTR
GPS
ACC & DTG BIAS UPDATE
QTRN PROPGN
AIDED NAV KF
TM
Crctn
IMU
2 DTGS
3 ACCS
COMP S/W
NAVIG ATION
R, V
+
−
GUIDANCE
MAR1750 PROC
INITIALIZATIONS UPLINK VEL, POS, COEFFS,...
GROUND SEGMENT

Salient Features

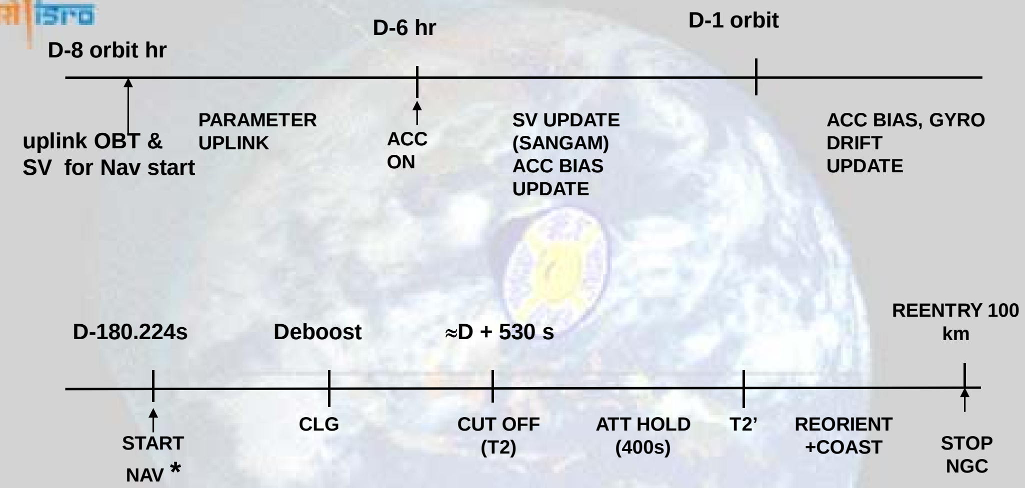
1. Mission requirement : Impact point error due to NGC : 25 km Demand on navigation : 0.36 m/s, 130m at thrust cutoff (D_0 + 535 sec nominal).
2. Inertial navigation (in ECI) is used for the deboost phases
   i) DBM 1: Circular to Daily repeating Orbit (REO)
   ii) DBM 2: REO to Reentry (100 km).
3. Mission is very sensitive to navigation inaccuracy
   250μg : 106km in Down range
   initial state vector error : 1.8 m/s : 133 km Down range
4. Navigation accuracy is improved by GPS aiding.
5. GPS data validation before using. Mission with pure INS in case of any error.

Salient Features …

6. No redundancy in sensors.
7. The gyros and quaternion propagation in all the phases
8. The accelerometers are put on for deboost purpose and the accelerometer bias are updated on orbit by software.

10. The deboost point is decided in the ground by the deboost mission planning and time and state vector are up linked.
11. The starting of execution is achieved by time polling logic in the scheduler/sequencer.

Sequence of Operation of Navigation (Typical)



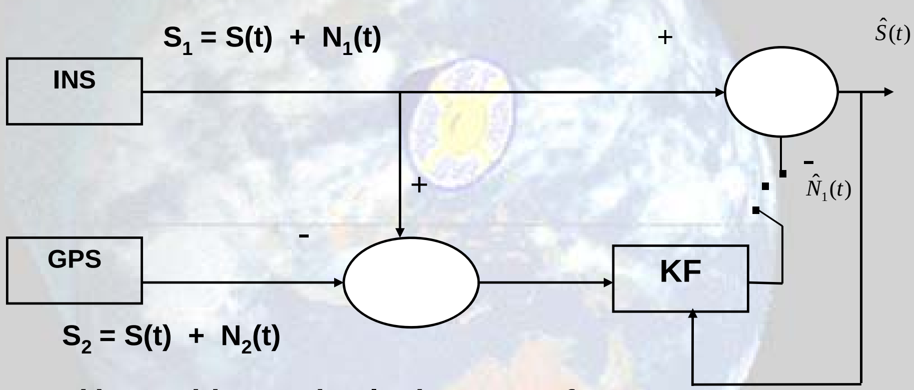
* : Super cycle boundary (pre-decided by ground mission planning)

Navigation software used in the two deboost phases with CLG.

i) DBM 1 : Circular to daily Repeating Elliptical Orbit (REO)

ii) DBM 2 : Deboost (from REO) to reentry (100km)

GPS Aided Navigation



$N_2(t)$: position and velocity error of GPS

$N_1(t)$: position and velocity error of INS

Design Features

- **12 state KF : INS error states.**
- **No feed back to INS : position, velocity error states used to correct the INS data in forward path.**
- **Enable/disable GPS aiding by ground command.**
- **INS data ensured to guidance under KF not started or stopped due to any error condition.**
- **KF start logic : 5 GPS samples required.**
- **Time update : 512ms**
- **Measurement update : as and when GPS data available (1 sec GPS update) after GPS validation.**

Design Features..

- Synchronization scheme for GPS data(1sec) with INS data (512msec) using time tag of data & Acceleration
- GPS data integrity/validation
- Plant model design & validation for KF
- Process and measurement noise estimation (Q,R)
- Kalman gains are stored onboard and scheduled based on time and events

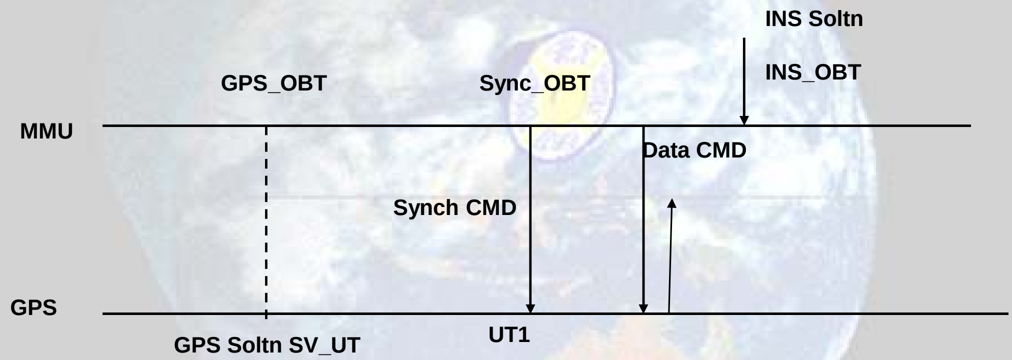
GPS data integrity checks

- **Data checks before use by KF**
  - Done by Data acq. & preprocessing
  - GPS integrity/checksum check
  - GPS receiver (hardware) check
  - Availability of fresh solution
  - Availability of solution in 3D mode
  - GPS PDOP checks (PDOP < 10)
  - KF gets synthesized status (data ready)

Error handling: GPS Aiding

- **GPS data validation by KF before usage**
  - GPS data loss handling(revert to INS if loss > 50s consecutive)
  - Rejection of GPS wild sample [(measured - predicted) > limit]
  - Stop aiding on persistence of any error (50s)
  - KF prediction mode under data loss after extended convergence.
  - INS data correction start only after 75sec of KF running.
- Start of KF only when GPS data is available (5 samples continuous)

GPS- INS DATA Synchronization



GPS SV is projected to INS time instant using INS acceleration.

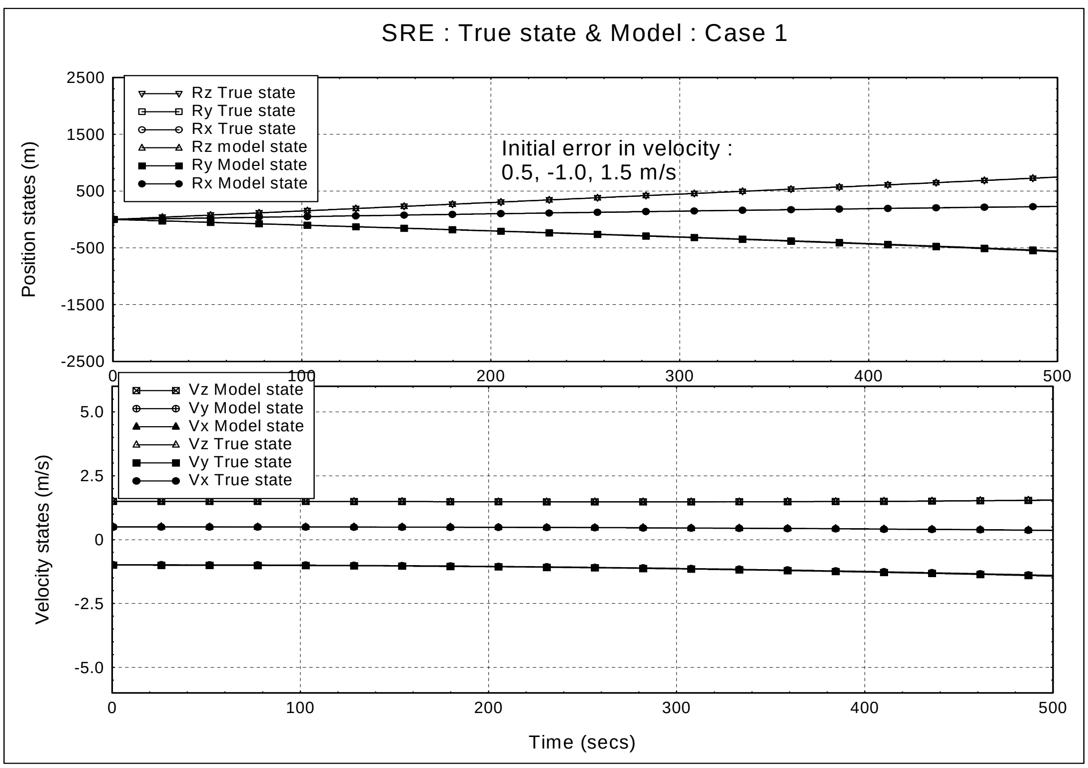
Kalman Filter states

• **INS Position error**	:	**3**
• **INS Velocity error**	:	**3**
• **System misalignment**	:	**3**
• **Accelerometer bias**	:	**3**

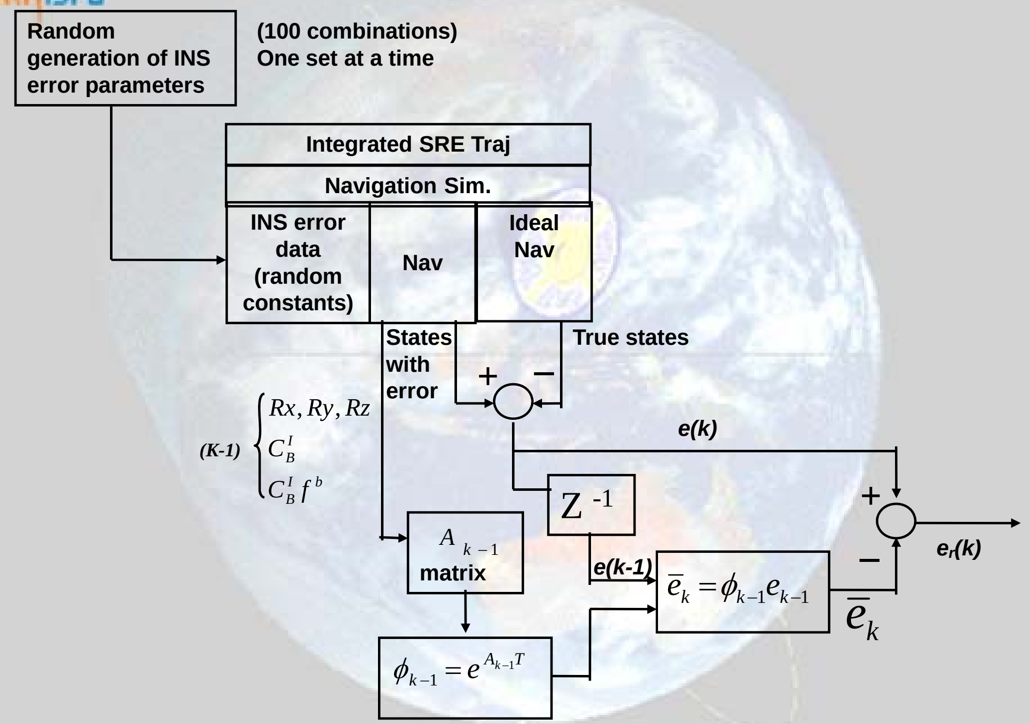
- The input (measurement) to the Kalman filter is (INS-GPS). The states of the filter are the error states. The model for the Kalman filter is the error dynamics of the inertial navigation system.
- The error dynamics model was designed analytically and validated by simulation.
- The effect of all un-modeled errors are accounted in process noise covariance matrix (Q).
- Measurement noise covariance (R) is specified based on data from IRS missions and receiver testing with RF simulator.

Model Validation

- The 12 state model $X(K+1) = \phi k\ X(k)$ is validated by simulation by incorporating the modeled errors in INS and propagating through the trajectory.
- Model validation results give adequate accuracy.
- Q is estimated from statistics of single step prediction error under perturbation of all INS errors over the trajectory for various cases.



Q : Estimation procedure



Scheduling of KF gains

- **On line computation of gains could not be accommodated in real time.**
- **Stored gain with scheduling based on events and time is selected as** follows.

12 gains	:	before cutoff (T2)
1 gain	:	for attitude hold phase (T2 to T2')
4 gains	:	reorientation/coast till reentry (T3)

- Separate gain schedule used for REO and Deboost phases.

Design Validation

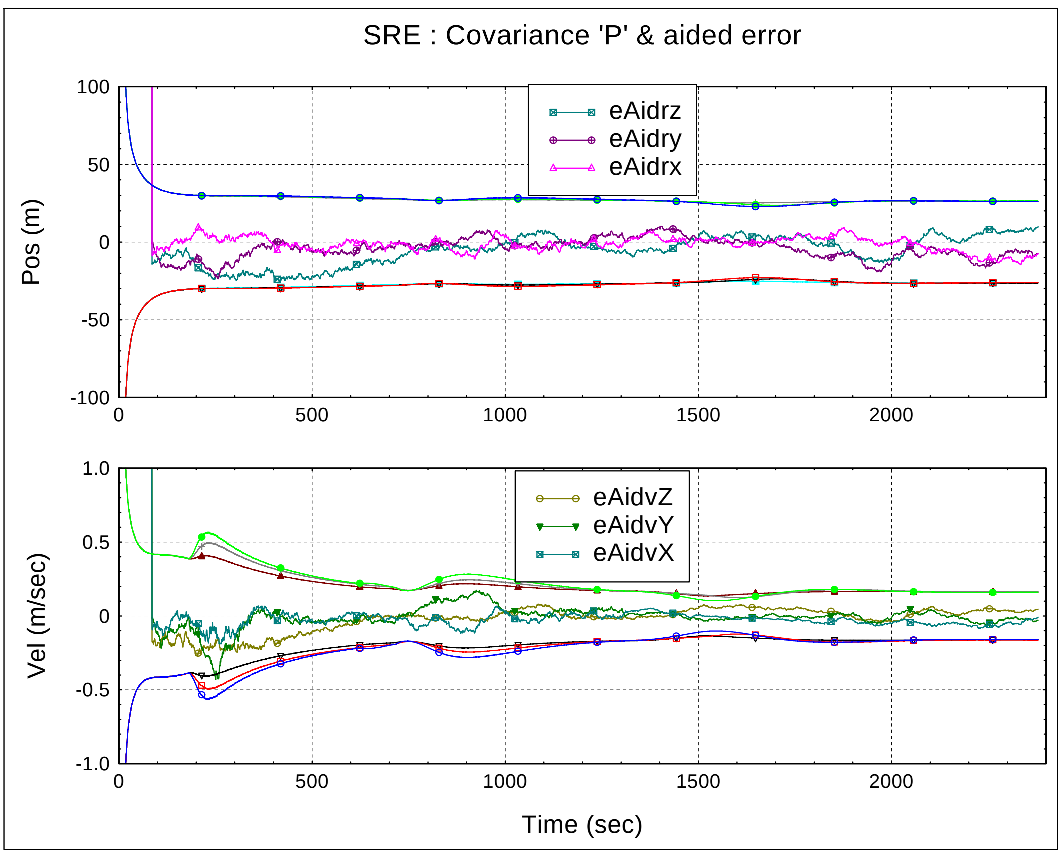
Perturbation studies by simulation

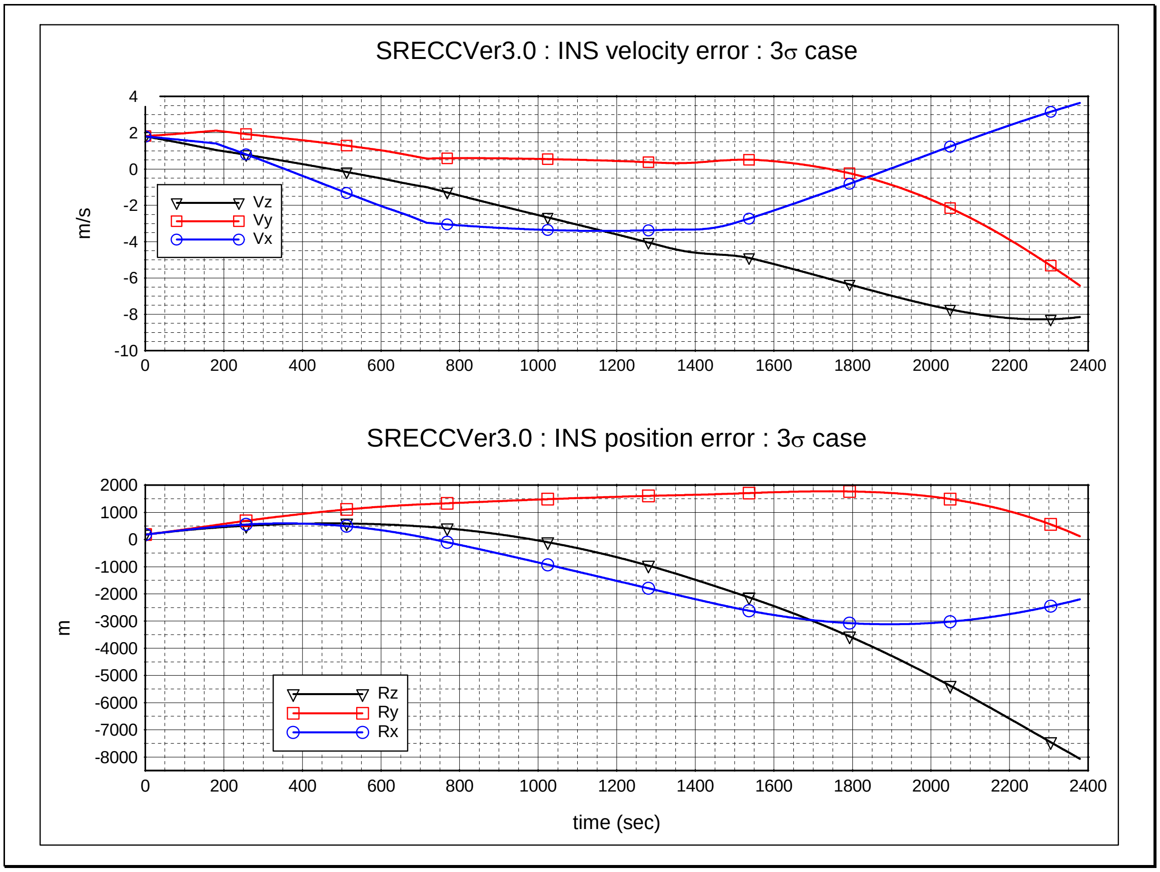
- Up to $\pm 12\sigma$ INS & GPS errors
- $\pm$32% thrust perturbation
- GPS data loss
- GPS data with wild samples
- KF gain perturbation
- Q perturbation

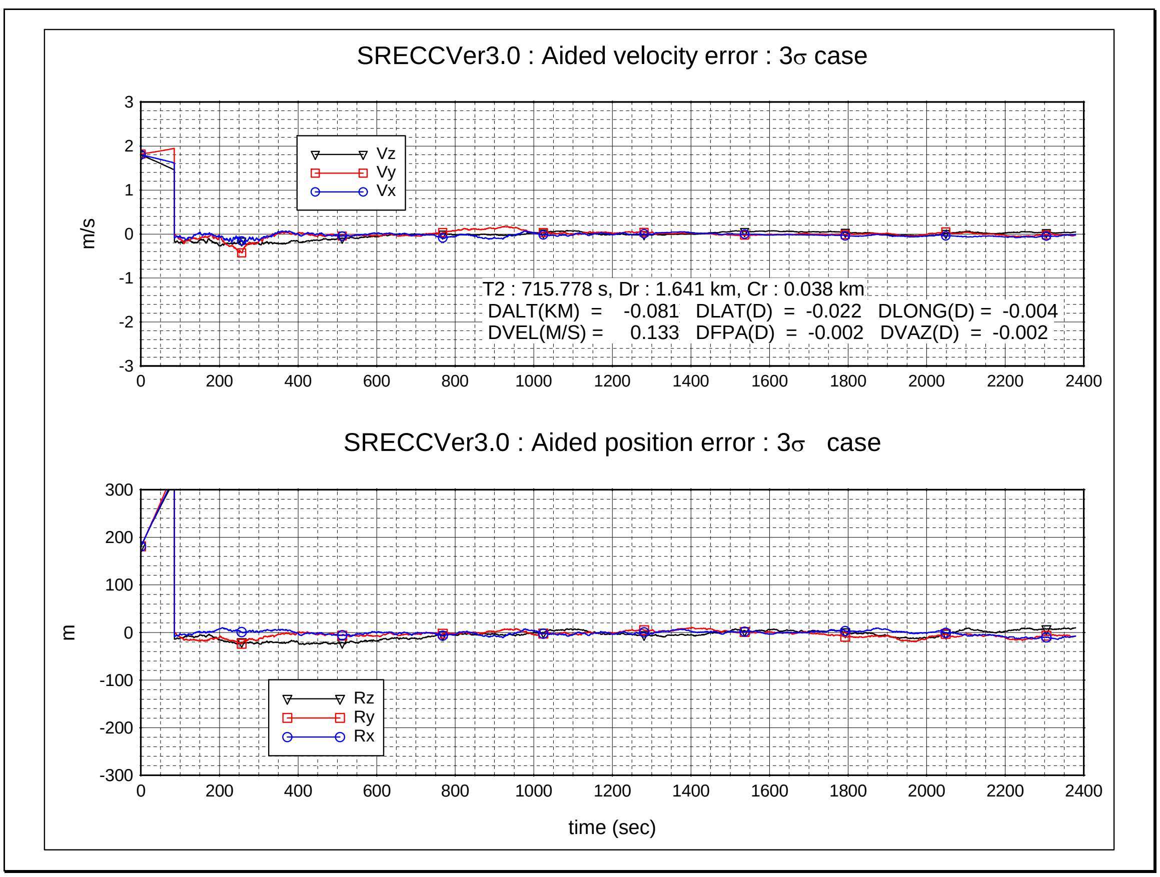
Aided Navigation performance

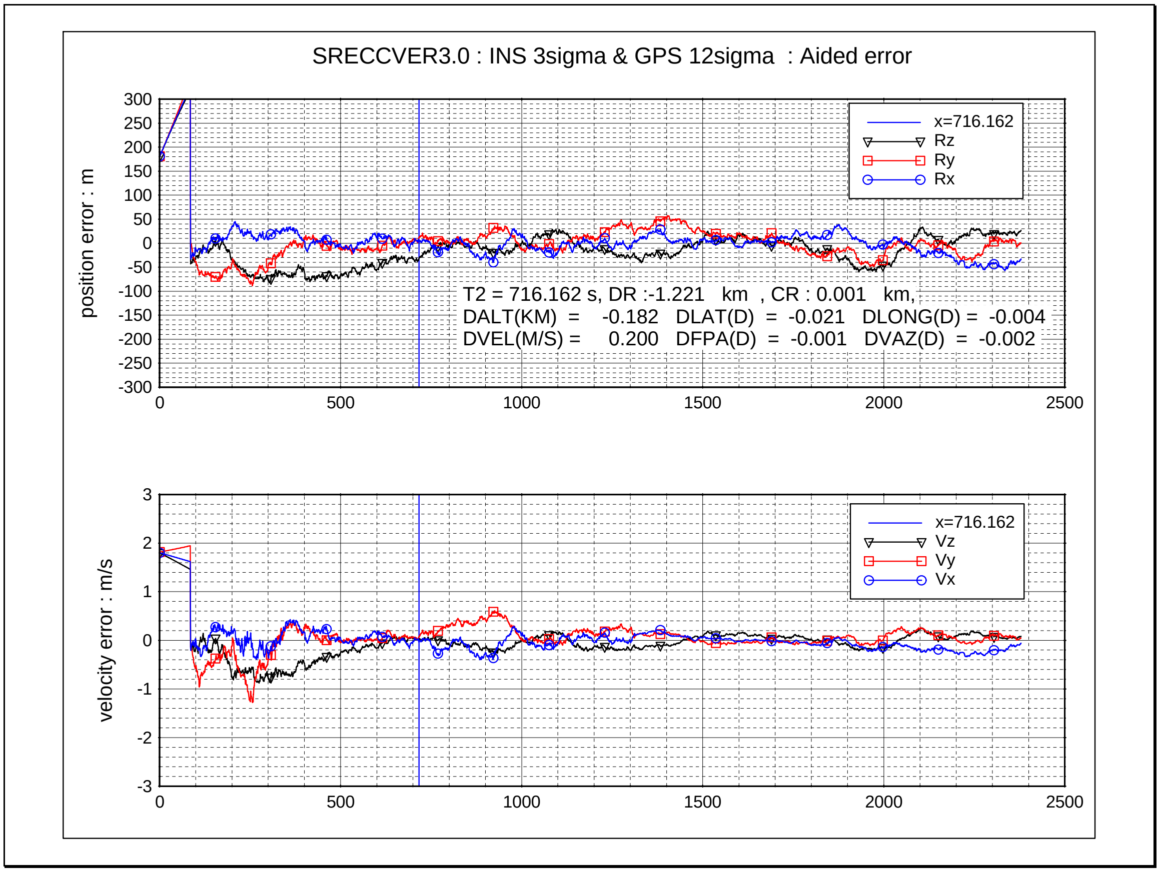
autonomous simulation for various perturbation levels of INS sensors, GPS, initial attitude errors, initial state vector errors

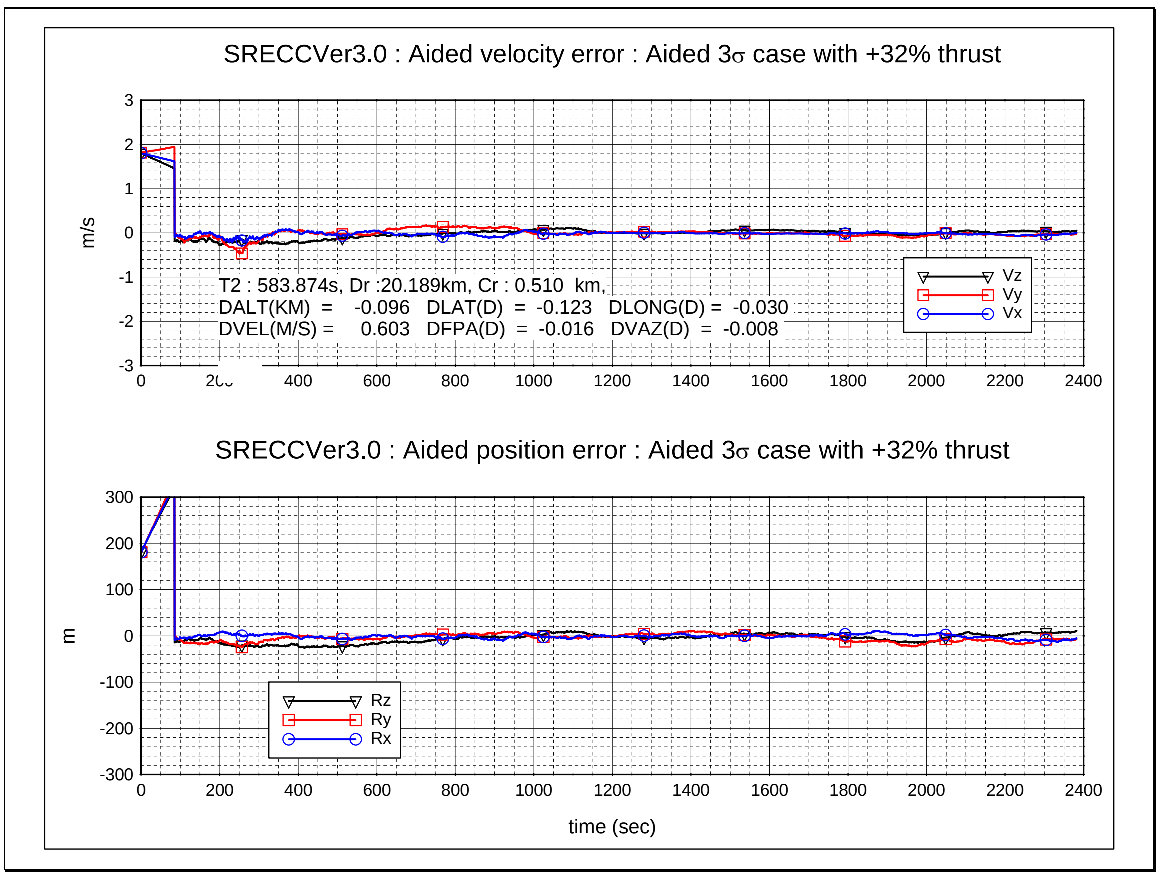
Velocity error : 0.2 m/s (unaided 5 m/s)
Position error : 30 m (unaided 8 km)

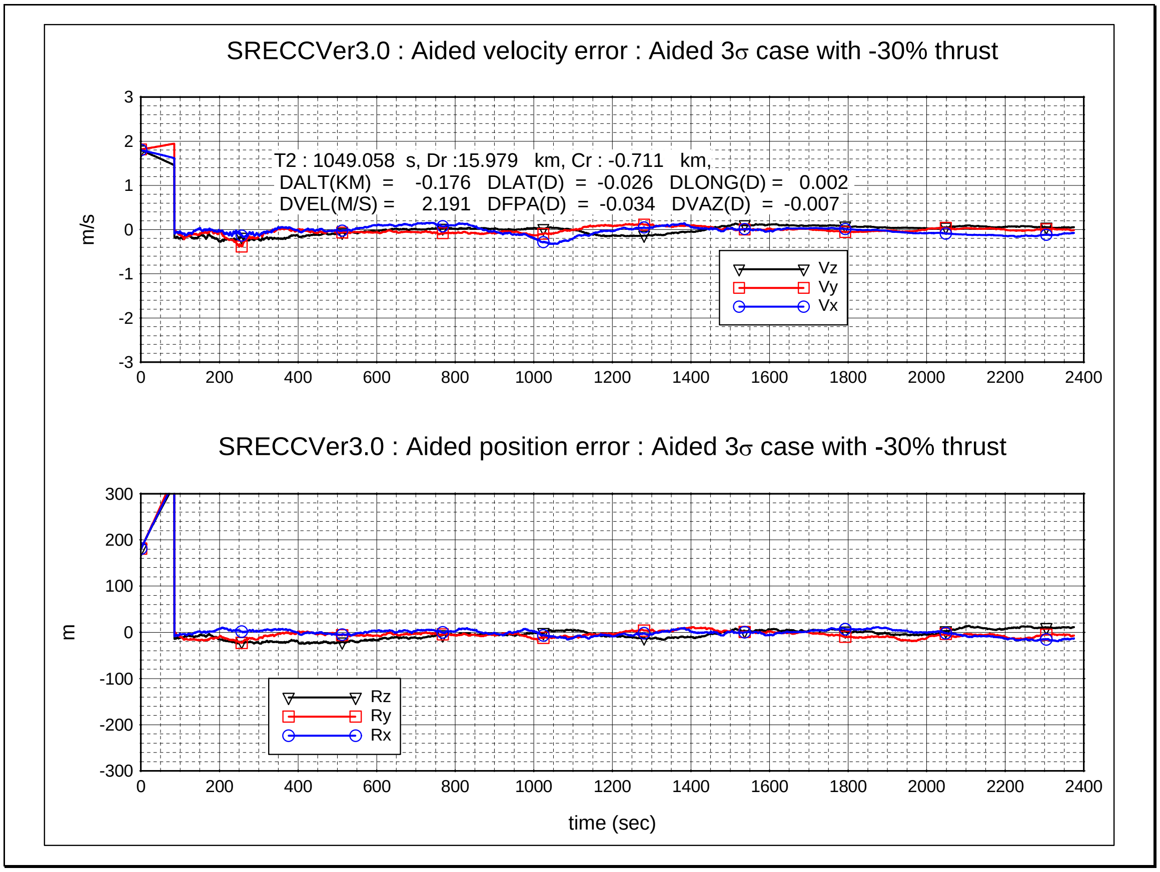


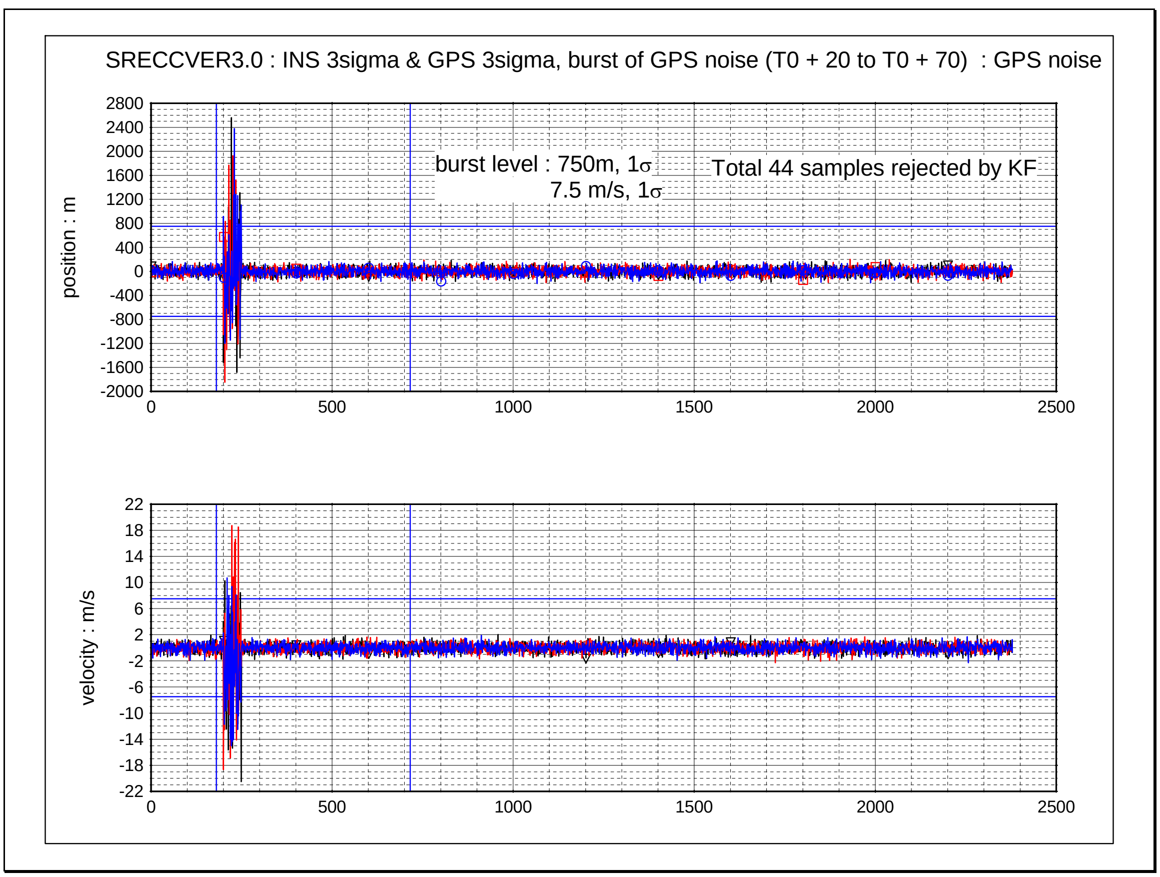

SRECCVer3.0 : INS velocity error : 3σ case
m/s
Vz
Vy
Vx
SRECCVer3.0 : INS position error : 3σ case
m
Rz
Ry
Rx
time (sec)

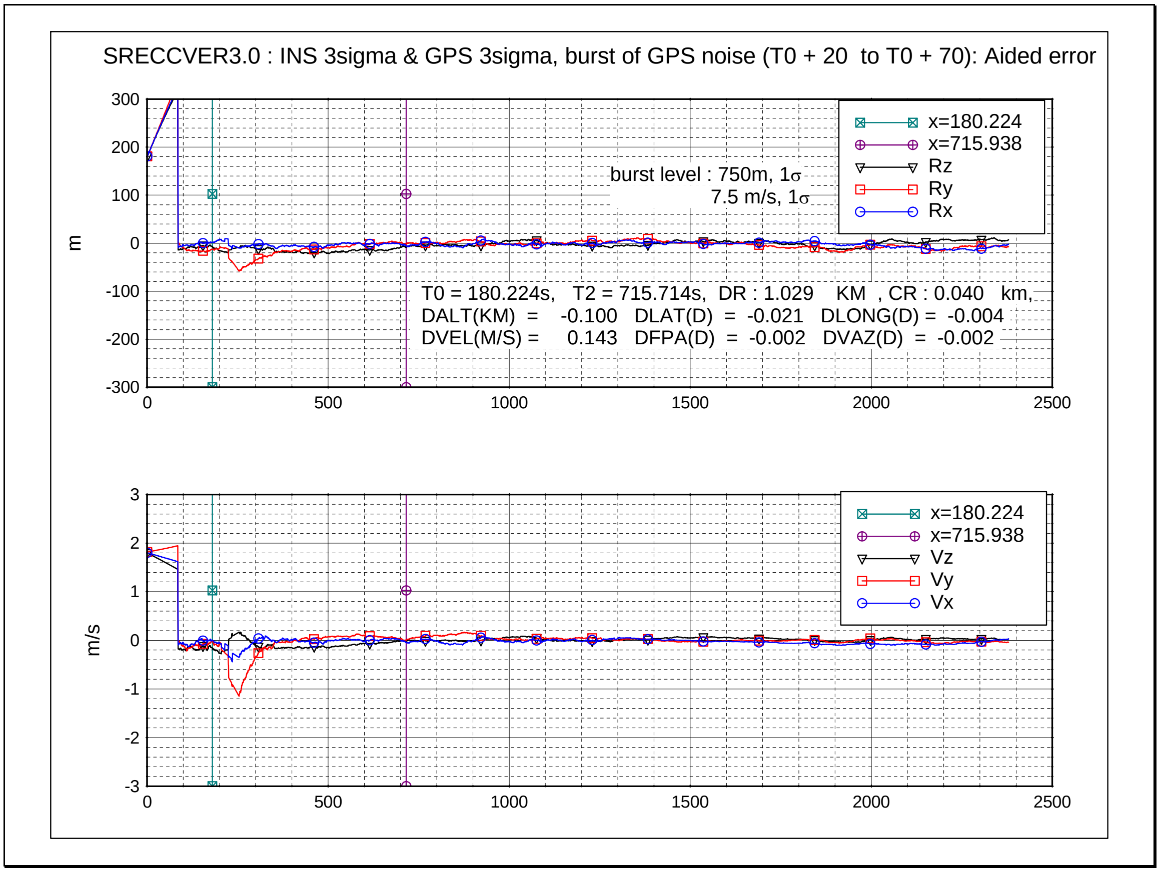

SRECCVer3.0 : Aided velocity error : 3σ case
m/s
Vz
Vy
Vx
T2 : 715.778 s, Dr : 1.641 km, Cr : 0.038 km
DALT(KM) = -0.081 DLAT(D) = -0.022 DLONG(D) = -0.004
DVEL(M/S) = 0.133 DFPA(D) = -0.002 DVAZ(D) = -0.002
SRECCVer3.0 : Aided position error : 3σ case
m
Rz
Ry
Rx
time (sec)

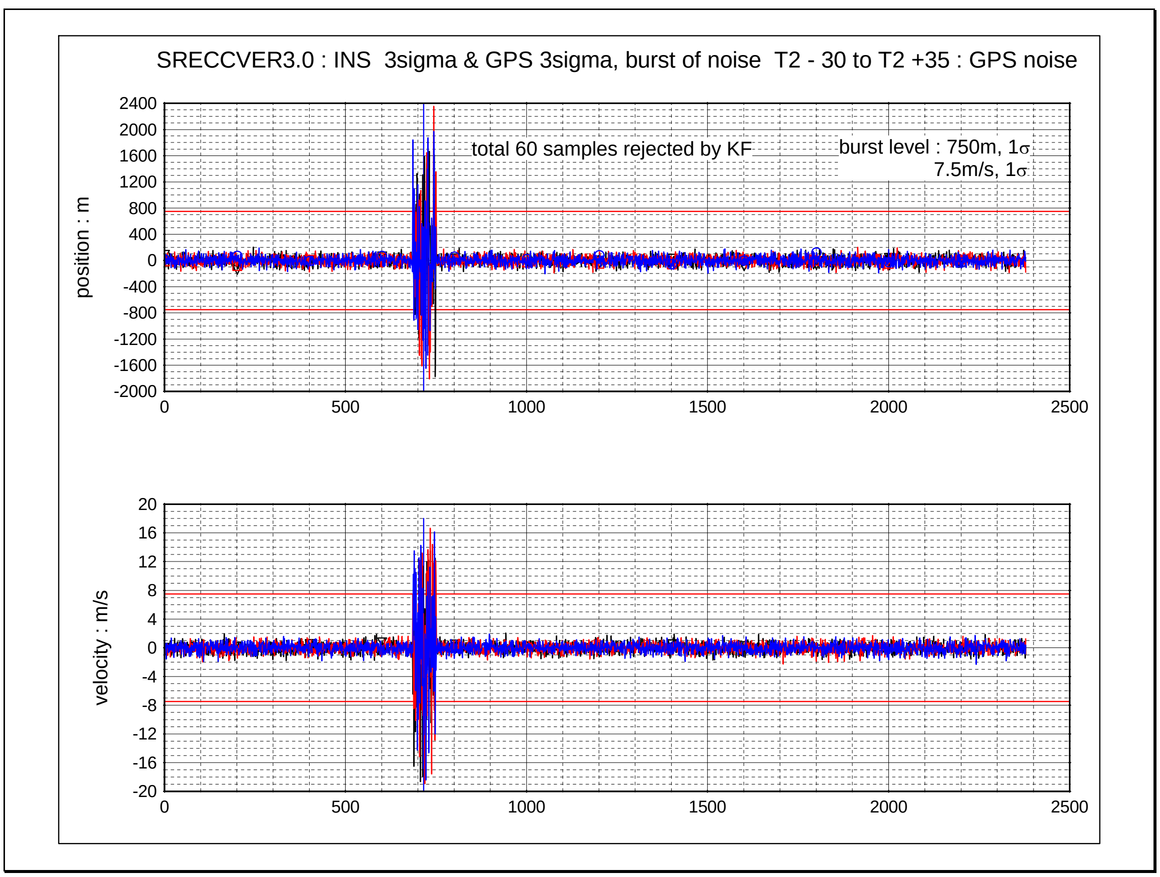

SRECCVER3.0 : INS 3sigma & GPS 12sigma : Aided error
position error : m
x=716.162
Rz
Ry
Rx
T2 = 716.162 s, DR :-1.221 km , CR : 0.001 km,
DALT(KM) = -0.182 DLAT(D) = -0.021 DLONG(D) = -0.004
DVEL(M/S) = 0.200 DFPA(D) = -0.001 DVAZ(D) = -0.002
velocity error : m/s
x=716.162
Vz
Vy
Vx

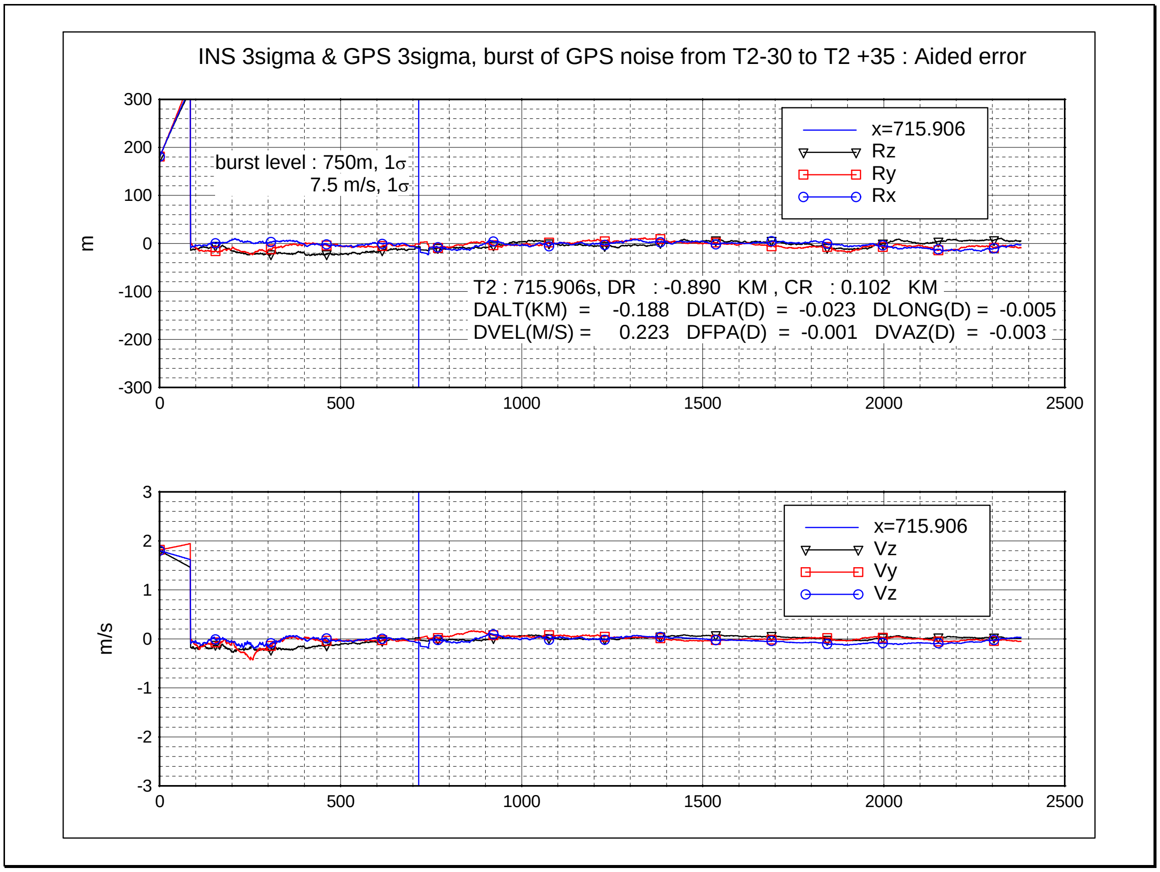

SRECCVer3.0 : Aided velocity error : Aided 3σ case with +32% thrust
m/s
T2 : 583.874s, Dr :20.189km, Cr : 0.510 km,
DALT(KM) = -0.096 DLAT(D) = -0.123 DLONG(D) = -0.030
DVEL(M/S) = 0.603 DFPA(D) = -0.016 DVAZ(D) = -0.008
Vz
Vy
Vx
SRECCVer3.0 : Aided position error : Aided 3σ case with +32% thrust
m
Rz
Ry
Rx
time (sec)

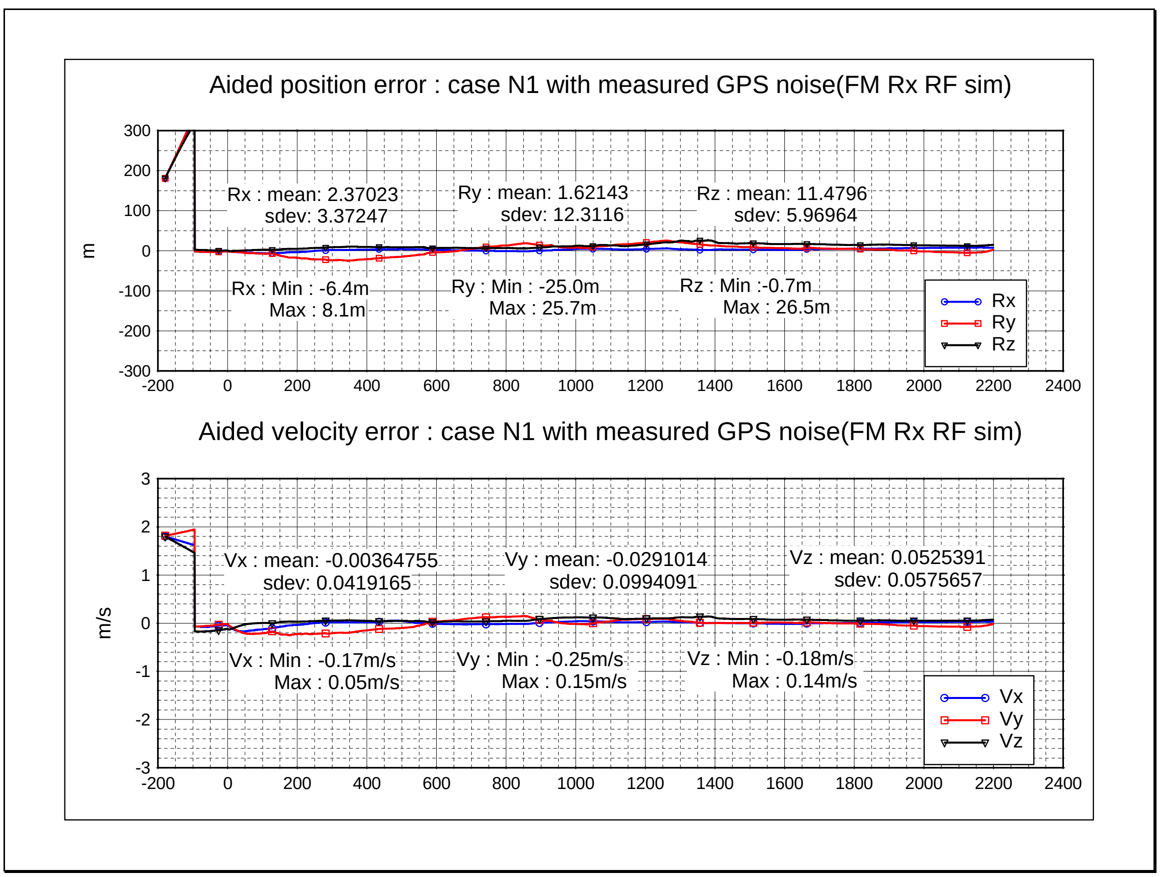

SRECCVer3.0 : Aided velocity error : Aided 3σ case with -30% thrust
T2 : 1049.058 s, Dr :15.979 km, Cr : -0.711 km,
DALT(KM) = -0.176 DLAT(D) = -0.026 DLONG(D) = 0.002
DVEL(M/S) = 2.191 DFPA(D) = -0.034 DVAZ(D) = -0.007
Vz
Vy
Vx
m/s
SRECCVer3.0 : Aided position error : Aided 3σ case with -30% thrust
Rz
Ry
Rx
m
time (sec)


SRECCVER3.0 : INS 3sigma & GPS 3sigma, burst of GPS noise (T0 + 20 to T0 + 70) : GPS noise
burst level : 750m, 1σ
7.5 m/s, 1σ
Total 44 samples rejected by KF
position : m
velocity : m/s


SRECCVER3.0 : INS 3sigma & GPS 3sigma, burst of GPS noise (T0 + 20 to T0 + 70): Aided error
burst level : 750m, 1σ
7.5 m/s, 1σ
x=180.224
x=715.938
Rz
Ry
Rx
T0 = 180.224s, T2 = 715.714s, DR : 1.029 KM , CR : 0.040 km,
DALT(KM) = -0.100 DLAT(D) = -0.021 DLONG(D) = -0.004
DVEL(M/S) = 0.143 DFPA(D) = -0.002 DVAZ(D) = -0.002
m
m/s
Vz
Vy
Vx


SRECCVER3.0 : INS 3sigma & GPS 3sigma, burst of noise T2 - 30 to T2 +35 : GPS noise
total 60 samples rejected by KF
burst level : 750m, 1σ
7.5m/s, 1σ
position : m
velocity : m/s


INS 3sigma & GPS 3sigma, burst of GPS noise from T2-30 to T2 +35 : Aided error
burst level : 750m, 1σ
7.5 m/s, 1σ
x=715.906
Rz
Ry
Rx
T2 : 715.906s, DR : -0.890 KM , CR : 0.102 KM
DALT(KM) = -0.188 DLAT(D) = -0.023 DLONG(D) = -0.005
DVEL(M/S) = 0.223 DFPA(D) = -0.001 DVAZ(D) = -0.003
m
m/s
x=715.906
Vz
Vy
Vz


Aided position error : case N1 with measured GPS noise(FM Rx RF sim)
Rx : mean: 2.37023
sdev: 3.37247
Ry : mean: 1.62143
sdev: 12.3116
Rz : mean: 11.4796
sdev: 5.96964
Rx : Min : -6.4m
Max : 8.1m
Ry : Min : -25.0m
Max : 25.7m
Rz : Min :-0.7m
Max : 26.5m
Rx
Ry
Rz
m
Aided velocity error : case N1 with measured GPS noise(FM Rx RF sim)
Vx : mean: -0.00364755
sdev: 0.0419165
Vy : mean: -0.0291014
sdev: 0.0994091
Vz : mean: 0.0525391
sdev: 0.0575657
Vx : Min : -0.17m/s
Max : 0.05m/s
Vy : Min : -0.25m/s
Max : 0.15m/s
Vz : Min : -0.18m/s
Max : 0.14m/s
Vx
Vy
Vz
m/s

Onboard software verification and validation

- Software Requirements and FRD review
- Software design document
- Code inspection
- Unit testing and static integrated tests
- SIP offline and real time
- OILS testing(20 cases)
- HILS testing(5 cases)
- AIT
- Test results review

NGC error sensitivity SRETRAJ3.0 unaided INS Deboost to Reentry (100km)

Sl. No.	Parameter	Down Range (km)	Cross range (km)
1	XA Bias : 250 microg	28.599	0.594
2	YA Bias : 250 microg	106.411	0.872
3	ZA Bias : 250 microg	1.055	2.109
4	X gyro drift: 0.3 deg/hr	1.399	0.175
5	Y1 gyro drift : 0.3 deg/hr	1.228	0.054
6	Z gyro drift : 0.3 deg/hr	0.326	0.045
7	Initial Vx est : 1.8 m/s	19.704	-0.394
8	Initial Vy est : 1.8 m/s	0.271	0.425
9	Initial Vz est : 1.8 m/s	-132.899	-0.578
10	Initial Rx : 180 m	2.702	0.214
11	Initial Ry : 180 m	12.506	0.072
12	Initial Rz : 180 m	-0.471	0.053
13	Initial attitude est X : 3600arcs	3.582	3.213
14	Initial attitude est Y : 4500arcs	0.504	-0.025
15	Initial attitude est Z : 3600arcs	-28.754	-0.152

MC analysis Deboost to Touch down * With all perturbations

	Down Range (km)	Cross Range (km)
INS with GPS aiding (3σ)	± 26.5	± 4.5
INS standalone (3σ)	± 250	± 19

* : Integrated simulation By APMD

Mission Summary

SRE 1 is

Launched on : 10th Jan 2007

Capsule to deboost orientation & monitoring of accelerometer & Magnetometer : 15th Jan 2007

On Orbit Trial Nav : 18th Jan 2007
DBM1 (REO) : 20th Jan 2007
Deboost, Reentry, Recovery : 22nd Jan 2007

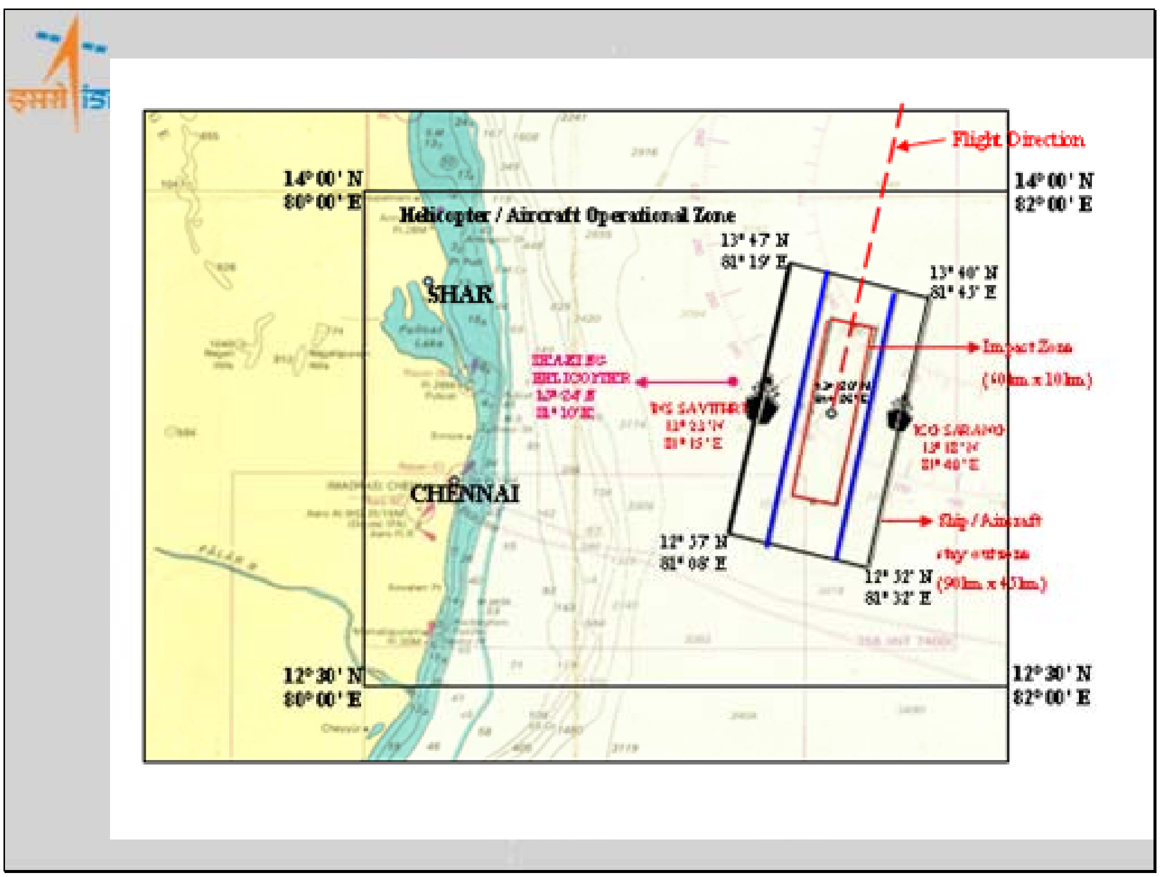
Aided Inertial Navigation is successfully used in Trial Nav, and in CLG for, DBM1, DBM2 for reentry.

REO accuracy : 15m Perigee

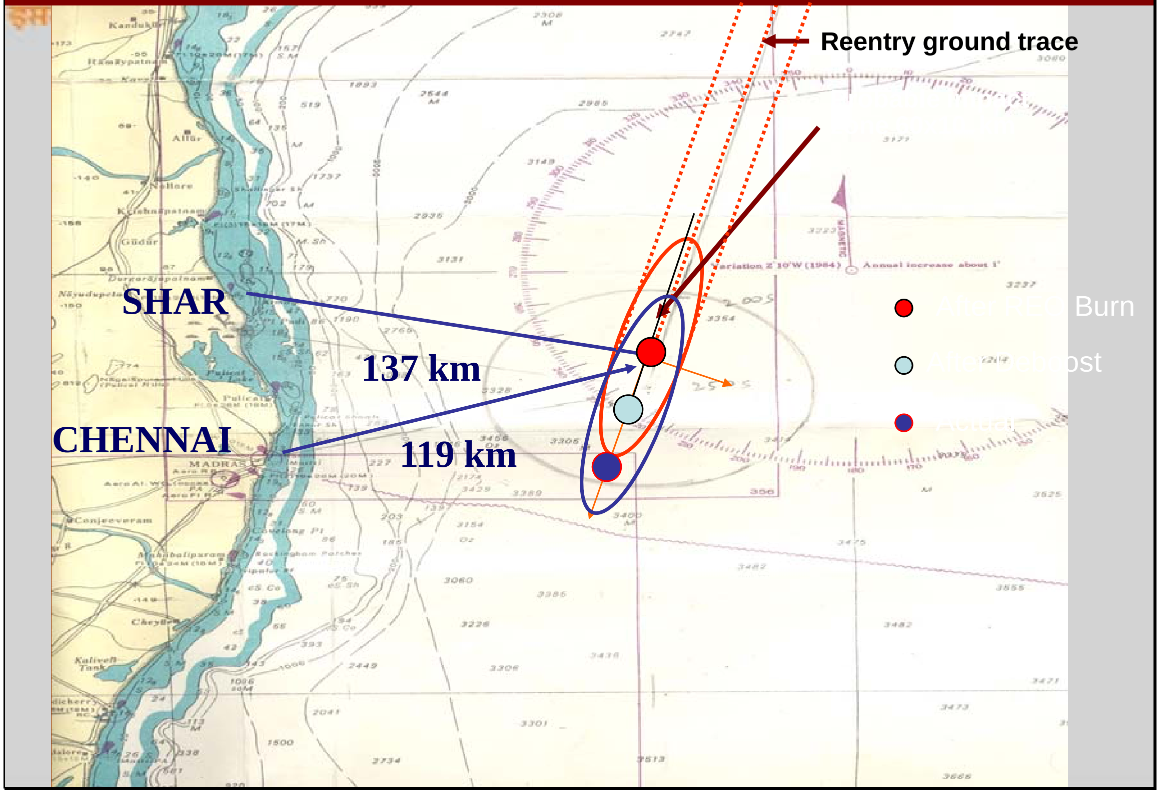
DBM2 Impact point accuracy : 4km (NGC alone)

Spec(3σ) : 25km

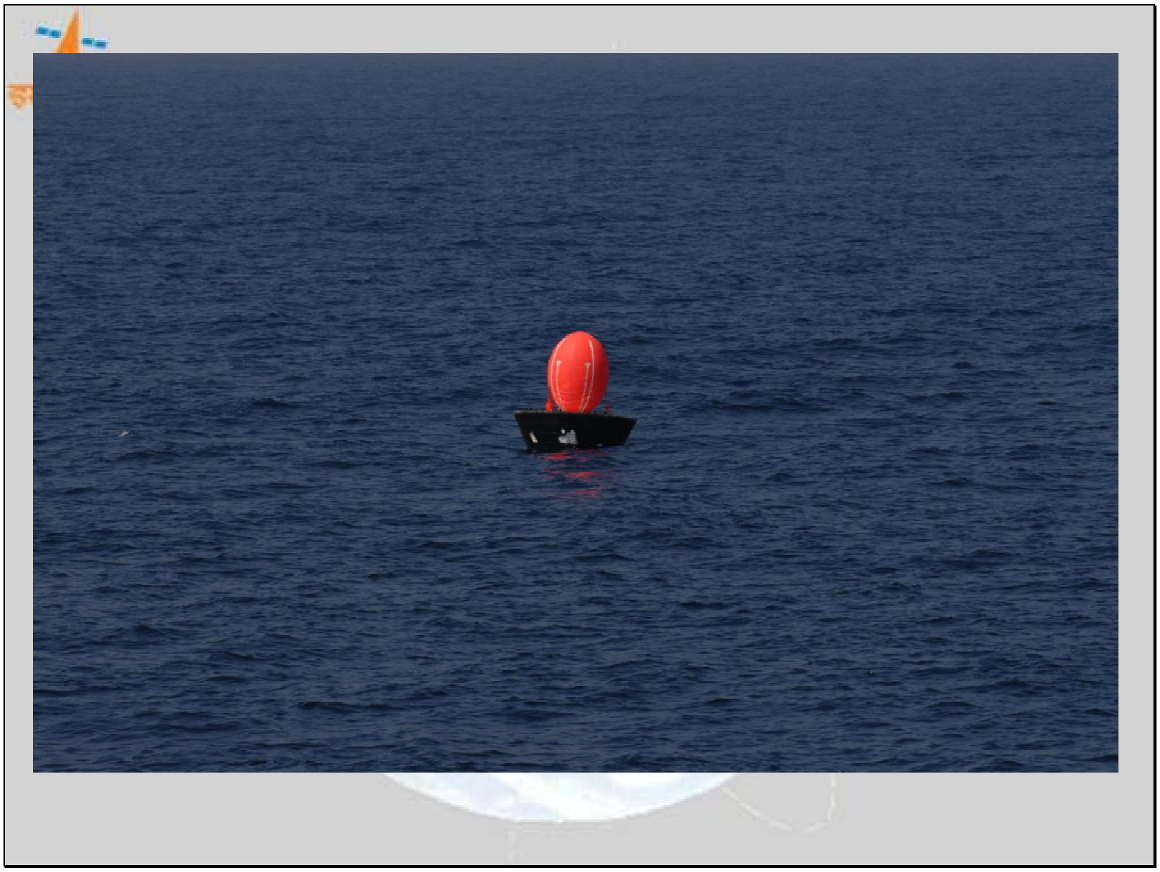

Recovery operation – External agencies involved
INS Brhammaputra
SARANG - ICG
Recovery ship
20 to 30 kts*, 20 days endurance
DRDL
SAVITRI - Navy
Ship born telemetry
SEAKING - Navy
Air born telemetry
100-120 kts
CHETAK - ICG
Pre recovery operations
90 kts, 2 hours endurance
* 1kts = 1.852 km/hr
DORNIER - ICG
180-200 kts, 6 hrs endurance
COAST GUARD
CG772


Flight Direction
14° 00' N
80° 00' E
14° 00' N
82° 00' E
Helicopter / Aircraft Operational Zone
13° 47' N
81° 19' E
13° 40' N
81° 43' E
SHAR
Impact Zone
(40km x 10km)
CHENNAI
Ship / Aircraft
(90km x 45km)
12° 57' N
81° 08' E
12° 32' N
81° 32' E
12° 30' N
80° 00' E
12° 30' N
82° 00' E

Impact point location



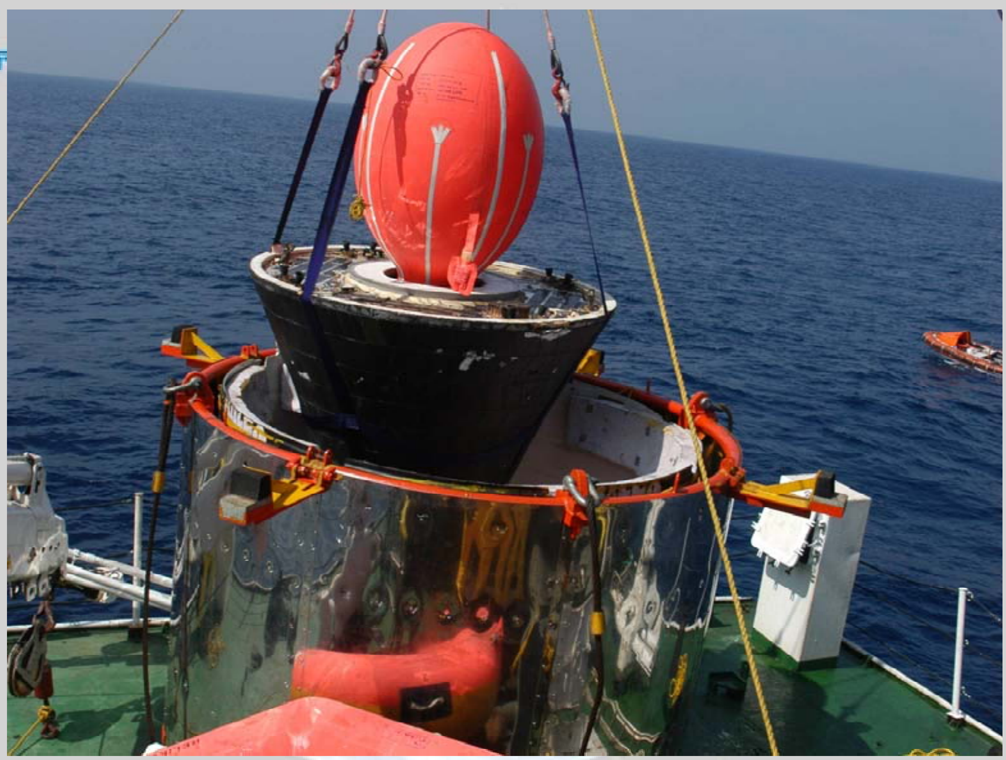
Capsule seen from distance



SRE – Photo taken from Chetak Helo

SRE being lowered into container

Close up view of nose cap



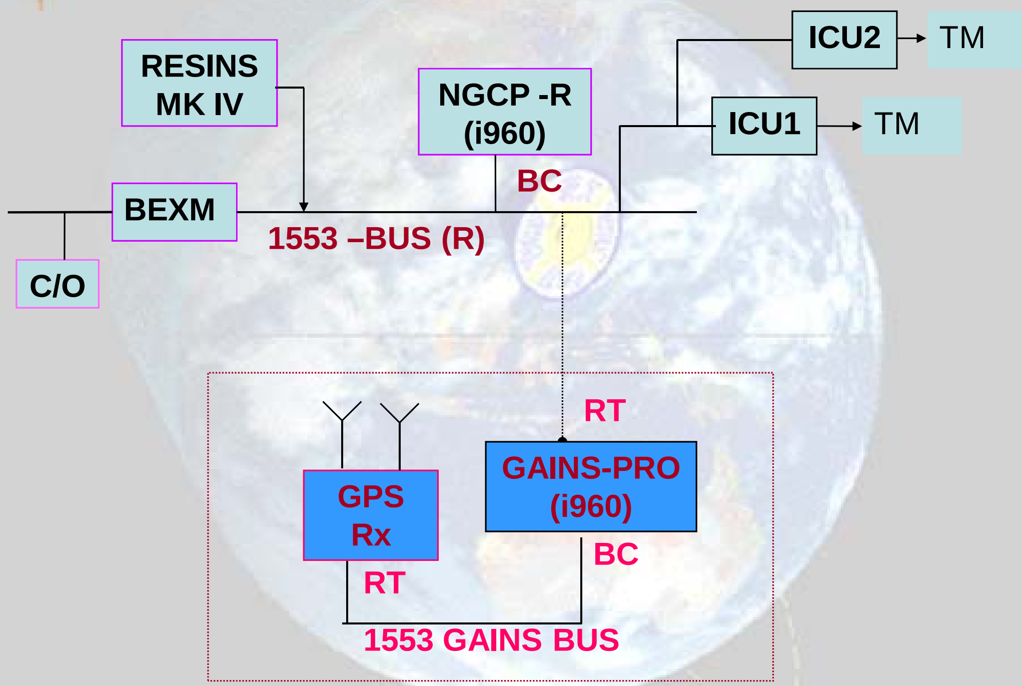
Part II

GPS Aided Inertial Navigation System for Launch Vehicle

Objectives

- Technology demonstration of GPS Aided INS (GAINS) on Piggyback in PSLV-C8 (2007)
- Enhance and evaluate performance of the existing RESINS system by GPS aiding
- Flight testing of a GPS receiver in the high dynamic trajectory of launch vehicle.
- Obtain accurate POD from GPS in real time which is independent of tracking data.
- Mastering of integrated navigation technology (INS +GPS/GLONASS etc) for future missions

GAINS- PSLV C8 - OVERALL CONFIGURATION



Major changes from SRE

- **High dynamic GPS receiver : 10.5 km/sec, 15 g , 20g/sec**
- Antenna configuration
- Visibility studies with measured antenna pattern, Flight trajectory
- 15 state Kalman Filter
- Real time Kalman gain computation

GAINS :GPS Receiver Performance

Time	No of Sat	PDOP	Position Fix/Loss
Pre Liftoff	5 to 8	2 to 4	3D
0 to 1300 s	6 to 8 Sat, PDOP < 5		3 s loss,2s at HS Sep, 1 s PS1 sep
1300 to 1500 s	6 to 7 : 148 s 4 sat : 2 sec 5 sat : 50 sec (PDOP 10)		No Loss

Aided Navigation Kalman Filter Performance

Kalman Filter Health : Normal

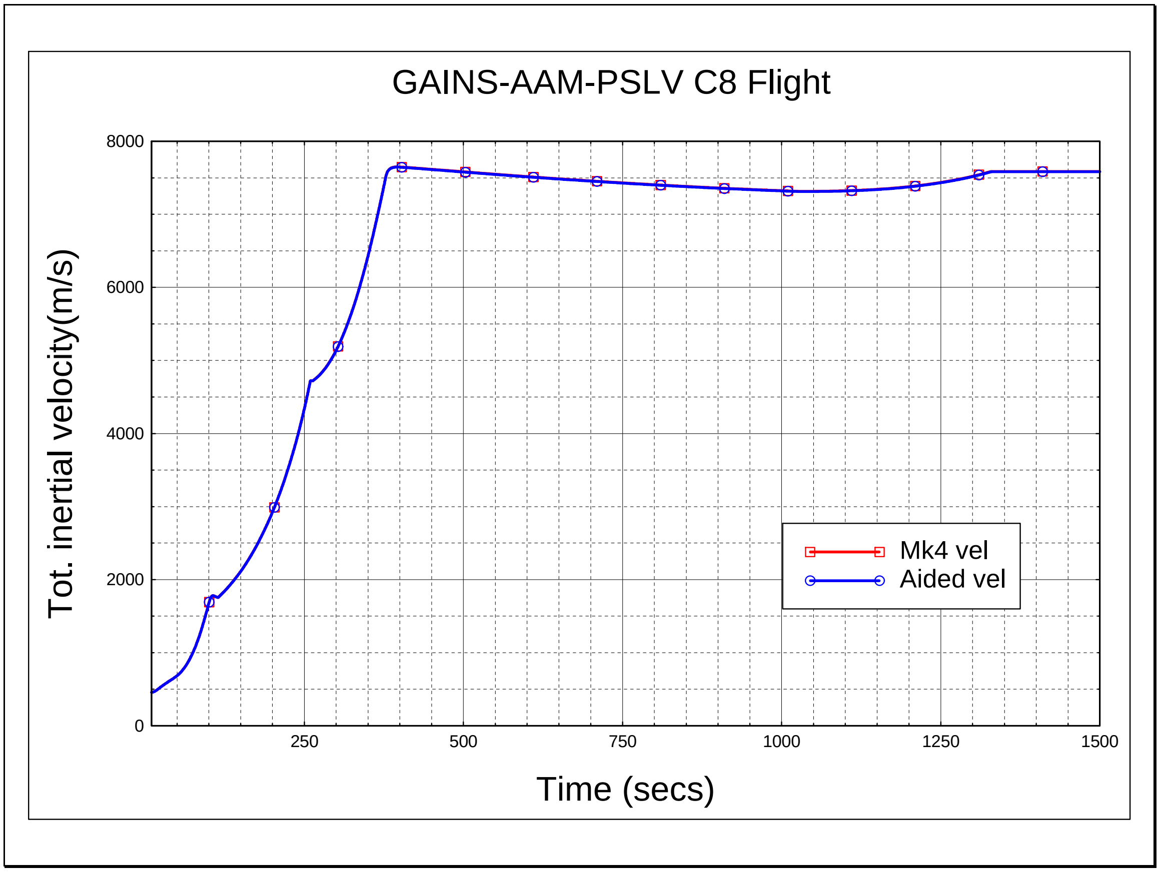
GPS 3D Nav Available from Lift off

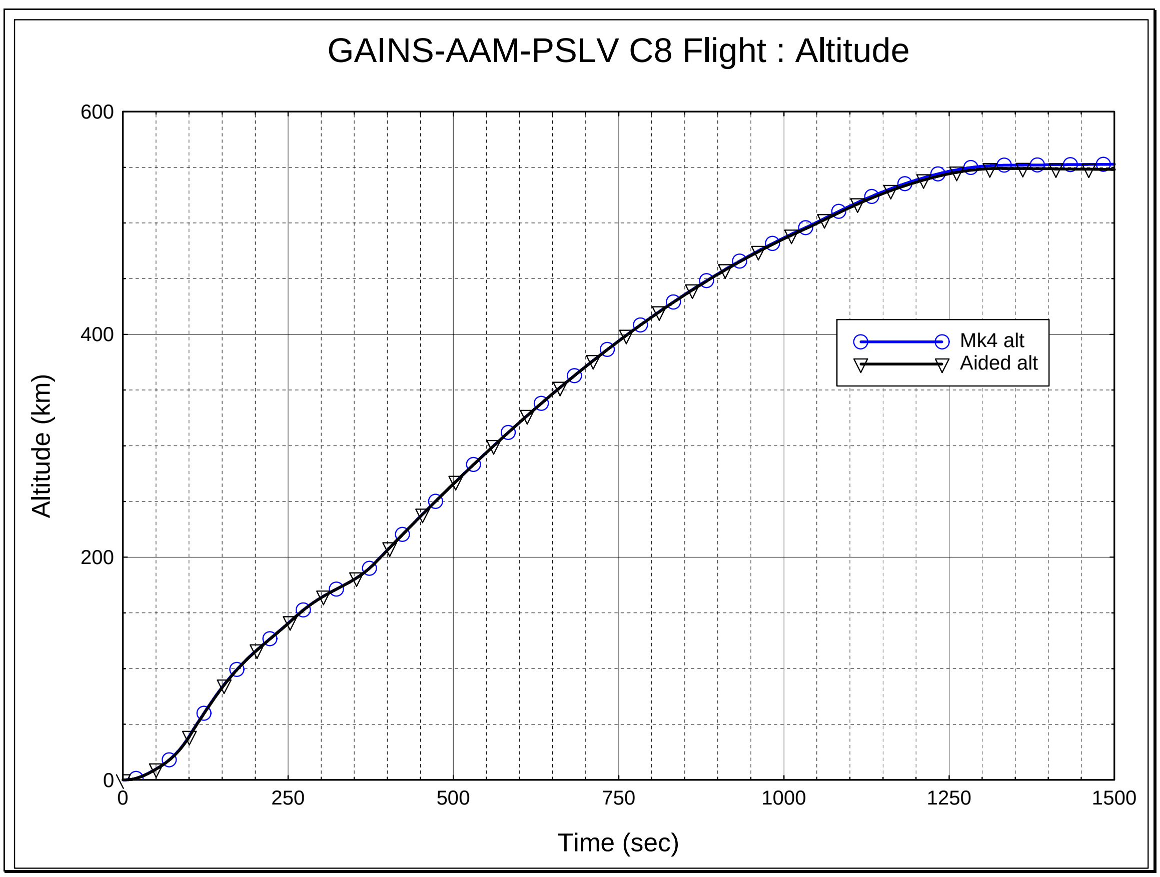
Kalman Filter Started at T + 10 sec

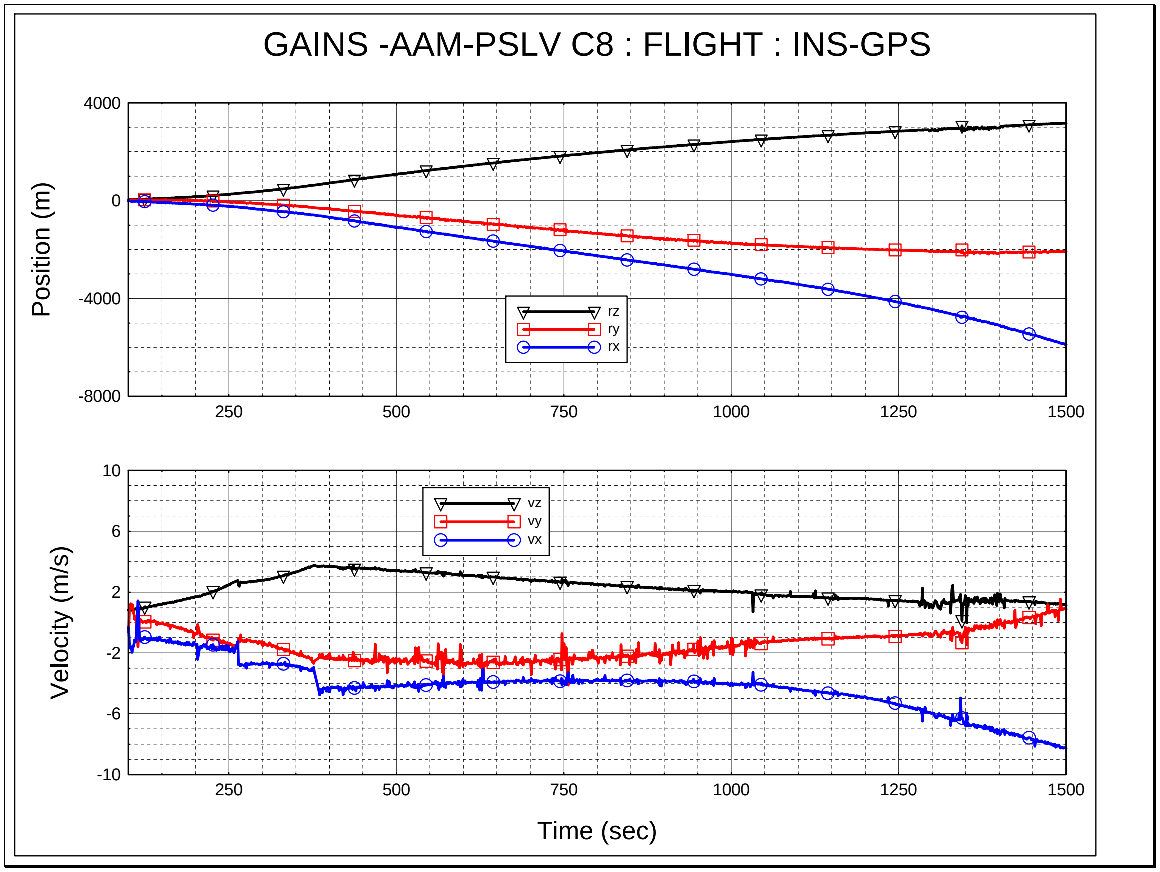
GPS Data Loss : 3 Samples

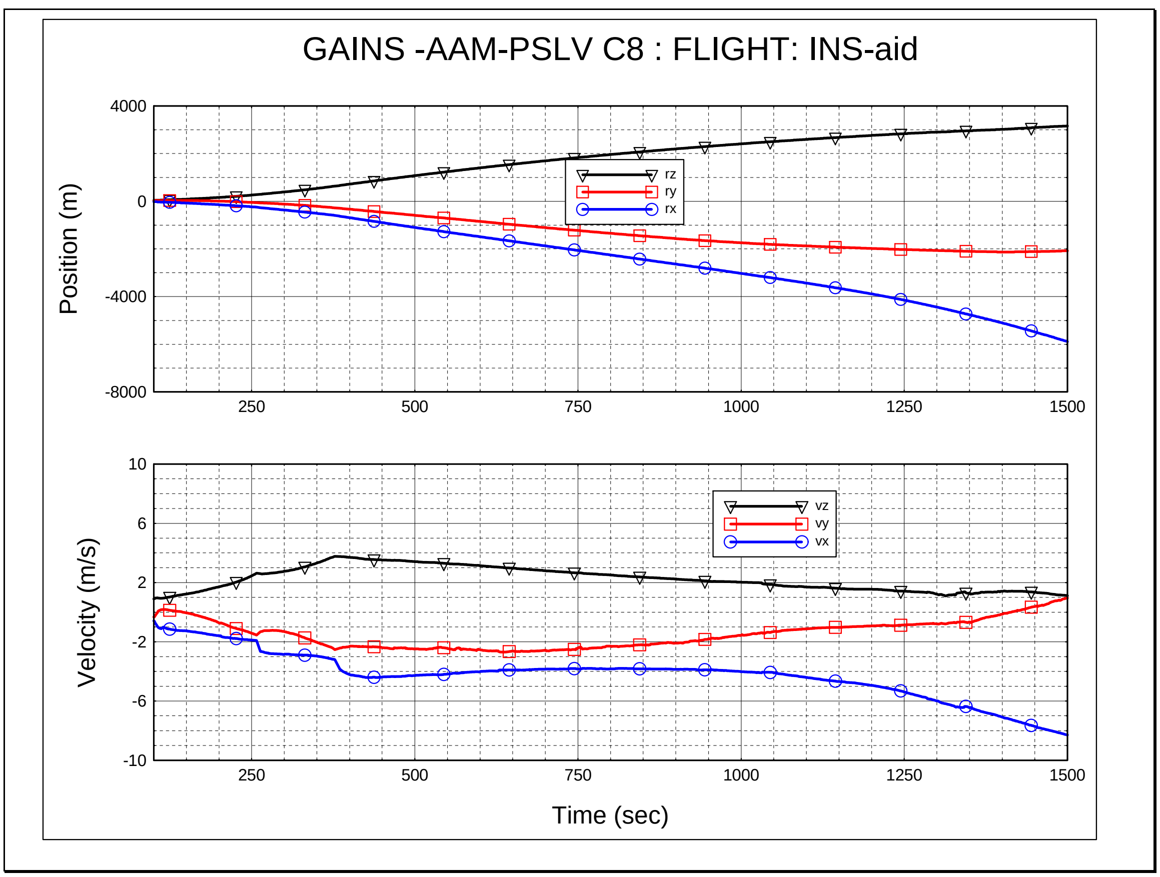
No of GPS Samples Rejected : Nil

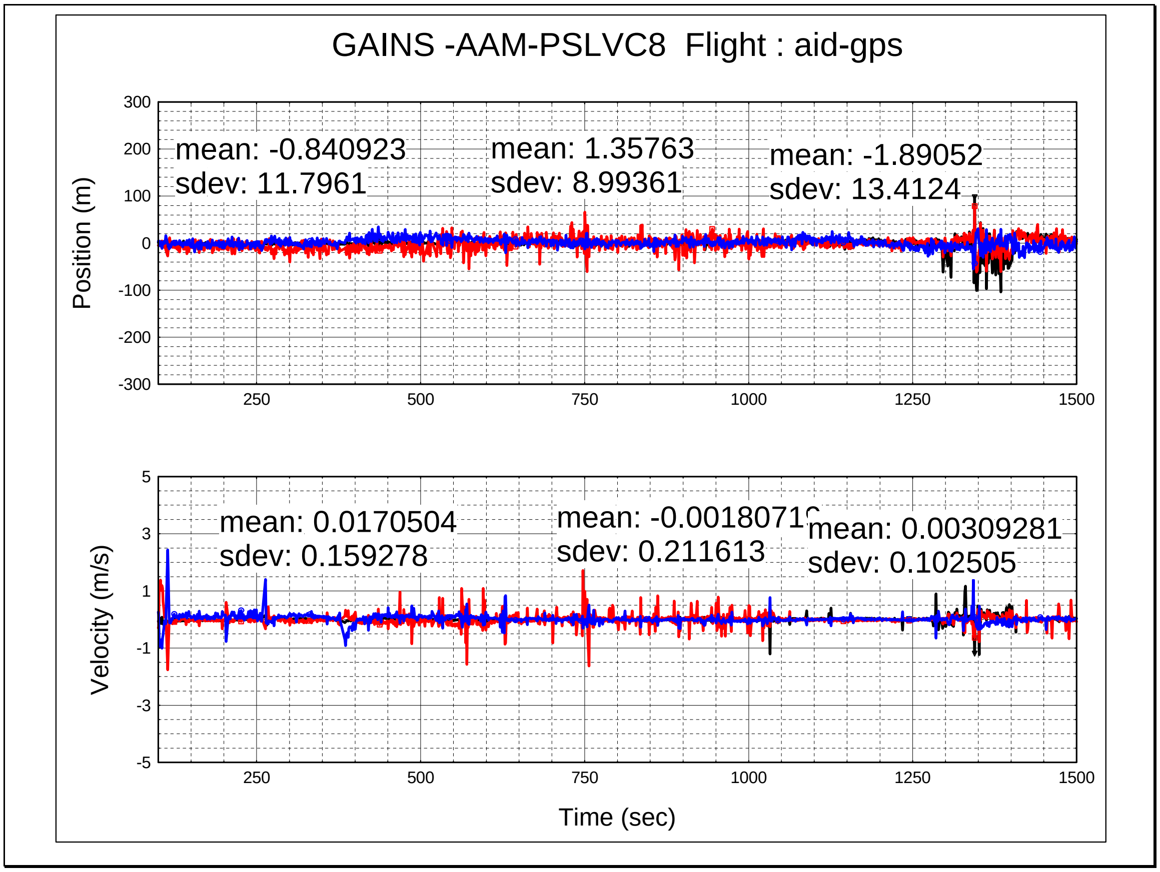
KF Covariance : Normal


GAINS-AAM-PSLV C8 Flight
Tot. inertial velocity(m/s)
8000
6000
4000
2000
0
250
500
750
1000
1250
1500
Time (secs)
Mk4 vel
Aided vel


GAINS-AAM-PSLV C8 Flight : Altitude
Altitude (km)
600
400
200
0
0
250
500
750
1000
1250
1500
Time (sec)
Mk4 alt
Aided alt


GAINS -AAM-PSLV C8 : FLIGHT : INS-GPS
Position (m)
4000
0
-4000
-8000
250
500
750
1000
1250
1500
rz
ry
rx
Velocity (m/s)
10
6
2
-2
-6
-10
vz
vy
vx
Time (sec)


GAINS -AAM-PSLV C8 : FLIGHT: INS-aid
Position (m)
4000
0
-4000
-8000
250
500
750
1000
1250
1500
rz
ry
rx
Velocity (m/s)
10
6
2
-2
-6
-10
vz
vy
vx
Time (sec)



Aided Navigation Performance

		INS Error Corrected (RESINS mk4 – Aided Nav)		
		X	Y	Z
T-4:30 hrs Static Nav (1200s)	Vel :m/s	**2.625**	**-5.998**	**3.87**
		Aided perf. : 18 m, 0.04 m/s		
	Pos : km	**2.372**	**-2.748**	**1.528**
Flight at 1371 sec	Vel :m/s	**-6.727**	**-0.418**	**1.348**
	Pos : km	**-4.901**	**-2.115**	**2.985**

Orbit error Comparison

	Apogee km	Perigee km	Inc Deg
AGILE TLE	550.278	538.704	2.4653
GAINS	550.643	538.813	2.471
RESINS	565.102	550.140	2.447
GAINS - RESINS	-14.459	-11.327	0.024
GAINS – TLE(REF)	0.365	0.109	0.0057

Conclusion

- ✓**Technology demonstration of GPS Aided INS (GAINS) on Piggyback AAM-PSLV-C8**
- ✓ **Performance of the existing RESINS system enhanced by GPS aiding**
- ✓**Flight testing of a GPS receiver in the high dynamic trajectory of launch vehicle.**
- ✓ **Accurate POD obtained from GPS & GAINS in real time which is independent of tracking data.**
- ✓**Mastering of integrated navigation technology (INS +GPS/GLONASS etc) for future missions**
- ✓**Based on the above, GPS aided INS is to be used in RLV TD(HEX) mission to meet the terminal phase accuracy requirement.**


End of presentation
&
Discussion

Speaker Profile

- B.E degree, Electronics & Communication, 1976, Madras University
- MTech degree, Applied Electronics & Instrumentation, Kerala University
- PhD degree in Computer Science, Kerala University, *“Stability based Optimal Fuzzy logic Controllers for nonlinear systems”*.

- Senior Member of IEEE.
- Life member System Society of India (SSI)
- Member Aeronautical Society of India (AeSI)
- Joined VSSC, March 1977, in Test & Evaluation Division, (Developed Test methods, test systems for testing electronic components for space applications).
- 1991 to 1993 : Quality assurance tasks of Launch Vehicle Avionic Systems for PSLV project.
- 1995-2001 : Control, guidance design group developing kalman filtering methods for various applications.
- 2002 onwards, Head of Navigation Software and Simulation Division of ISRO Inertial Systems Unit.
- Guided 30 MTech and B.Tech projects of Kerala & Bharathiar CUSAT & Calicut Universities.
- Research Interests include:
  - Intelligent control methods for nonlinear systems
  - Optimal filtering and control, Digital Signal Processing
  - Digital filter design using feedback neural network.
  - Inertial navigation algorithms and systems
  - Integrated Navigation Systems (Aided Inertial Systems)
  - Design of high dynamic navigation GPS, GLONASS, IRNSS receivers
- Currently, member of Post Graduate board of studies for Computer Science of the University of Kerala.

- 25 Research Publications (International Journals & IEEE Conference Papers), 200 Technical reports in ISRO R&D activities
- Books (1) Neuro-Fuzzy control, Narosa Publishing House, Delhi, 1998.

Awards: ISRO Team Excellence Award for the Development of Aided navigation system for Space Capsule Recovery Experiment, 2006.

Boeing

Summary of Panel Discussions

Future Directions and Research needs

The Panel members for the discussion were:

Dr. Kota Harinarayana, Dr. Raja Ramanna Fellow**,** NAL, Bangalore	Chairman
Dr. Ronald V Kruk, Chief Scientist, CAE, Canada	Member
Dr. PNAP Rao, Honeywell Technology Solution Pvt. Ltd., Bangalore	Member
Dr. Naveed M Hussain, Vice President**,** Engineering & Technology Boeing International Corporation, New Delhi	Member
Gp. Capt. Rajiv Kothiyal, VP Flight Operations**,** Air Deccan	Member
Capt. Gurudath., Indian Airlines	Member
Mrs. Padma Madhuranath, Head, FMCD, NAL, Bangalore	Member

The panel discussion was initiated by Dr. (Mrs) Girija Gopalratnam, Workshop Coordinator. In her opening remarks she mentioned (See the presentation slides) that the objective of the Panel discussions is to evolve a road-map for the Enhanced and Synthetic Vision (ESV) development for RTA-70 through creation of a network of organizations, both from India and abroad. She brought out some of the factors to be considered for achieving the high degree of reliability and redundancy expected from the Integrated Enhanced Vision System (IEVS). While she outlined the line of action envisaged for IEVS development at NAL, she sought the panel members to comment on the core issues like navigation data precision, real time monitoring of data base integrity, warnings for failures, guidance symbology for display on HUD/HMD and whether flight testing of intermediate developments is required before final integration of IEVS to the test aircraft.

The Chairman Dr. Kota Harinarayana began the panel discussions by thanking all the invited speakers for providing a fairly exhaustive overview of issues (both software and hardware) related to the development of IEVS. He reiterated that the aim is to develop a really affordable, robust, low cost system that should enable the low cost aircraft to land in unequipped airfields and thereby provide connectivity to all the airfields in India.

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He sought the panelists to comment on four major issues:

1. Specification of requirements for IEVS - This is the primary issue to be addressed. For a successful technology, all the requirements should be properly defined and prioritized.
2. Certification issues - Road to certification needs to be defined. Issues like the types of modeling and simulation studies we need to carry out on simulation/test aircraft platforms with a group of pilots need to be sorted out.
3. Navigation requirements – FAA has certified INS/GPS with WAAS/LAAS for achieving CAT I operations. Under bad weather conditions, RTA should be able to achieve at least CAT III A operations. Whether this requires IEVS or some simple system or a more complex system needs to be debated and decided.
4. Platforms for testing the intermediate concepts - Use of the proposed integrated simulation environment and NAL's HANSA and SARAS aircraft for testing the concepts

The following is a detailed account of the Panel discussions based on the comments by the panel members.

Dr. Ron Kruk mentioned that at CAE had similar concerns when the IEVS development started. He said that for defining requirements, it is essential to work in close contact with the users/pilots right from the beginning. This is the approach CAE adopted during their helicopter and military programs. He advised that opening of all 400 airfields should not be considered all at once but in a phased manner. An integrated approach to development is what is required in such programs. Aspects that require careful consideration are the kind of terrains (mountain side etc), the kind of approach facilities the airfields have and the kind of incursions to be avoided. It is necessary to evolve a whole lot of design criteria including several scenarios to be tested. Extensive testing should be carried out first in simulations and then in flight. Despite careful considerations, surprises do show up in simulator testing as well as in aircraft testing.

Commenting on the issue of certification, Dr. Kruk said that the FAA/NASA practice is to develop a roadmap for certification keeping safety and performance requirements in mind. There are many technologies around, however, we should choose a technology that is not too expensive, is simple to operate and maintain as well without extra servicing crew or ground support. For navigation solutions, Dr Kruk recommended selection of available technology in India, fully understand /consider issues of masking and design a system that functions well in our areas of operation

At this stage, Gp. Capt. Katiyal of MACMET commented that for an a/c to cross hilly terrains EVS may not be necessary and that GPS augmented with WAAS/LAAS would suffice for most of the tasks and IEVS which caters to only a few of the requirements could be purchased at a later stage. Dr. Kota answered that for all weather operations from unequipped airfields in India, IEVS is the solution. It is well known that even in Delhi airport where ILS exists, it is difficult to land in winter. We need to start parallel development of this technology for networking all the existing airfields while perfecting navigation with INS/GPS with LAAS/WAAS.

Gp. Capt. Rajiv Kothiyal indicated that the mission we are discussing for RTA is not navigation but landing in unequipped airfields. In India, Delhi is the only airfield with ILS system for CAT III landing and even here it is possible to achieve this only with a lot of ground support. Most of the airfields have at best VOR which is only a procedural aid and it is difficult to land under poor visibility conditions. What the pilots need is an aid to increase the Situational awareness (SA) by providing an out of the widow view in cloudy conditions and fog through synthetic vision. Transport aircraft landing is a predictable sort of situation. What is needed is increased SA under all weather conditions in all terrains. Gp. Capt. Kothiyal described the procedure for landing of transport aircraft under fog and cloudy conditions aided by INS/GPS and expressed the need for ESV to see through the clouds for approach and landing.

Gp. Capt. Rajiv Kothiyal mentioned that the situation in transport a/c is different from that for a fighter a/c. While in fighter a/c it is important to consider how much of the terrain the pilot can see, whether it should it be on a HUD or HMD etc, in transport a/c it is sufficient for the pilot to see that much of the airfield that he is using for landing. He exhorted that the pilot requirements should be clearly understood by the team looking at the design for evolving the road-map.

Gp. Capt. Katiyal again expressed that synthetic vision from a stored data may be sufficient and there is no need to have several sensor data merged. The problems of accuracy and maintenance for sensors and associated software could get quite formidable. Capt Gurudath also felt that it is difficult to maintain an aircraft with so many sensors and may be easier to maintain ground equipment instead. Dr. Kota said that Enhanced vision would provide the pilot with real time picture of the airfield as there could be errors in the data base. Further he added that in the LCA program they started with zero technology to evolve an aircraft with the most technologies. We need not be too overwhelmed by technologies and should evolve the one best suited to our requirements.

Dr. PNAP Rao emphasized the goal to achieve a low cost a/c (with 25% lower acquisition, maintenance) to operate in unequipped airfields under all weather conditions. There is a need to clearly define what is required for realizing this. Good avionics with good SA with HUD/HMD which will improve safety of the aircraft and Synthetic Vision (SV) is an answer for this. SV needs a good data base, ground features and cultural features (like buildings that come up between data base updates every 28 days). There is need to concentrate on getting 3D-terrain map generation for all airports. SV is sufficient for en route navigation but for approach and landing where high accuracy is required, Enhanced vision (EV) which is a real time information, gives a much more realistic picture than SV.

Dr. PNAP Rao mentioned that the accuracy of NAV information has to be ascertained so that it does not lead to “HMI” – “Hazardously Misleading Information”. Otherwise it may be more dangerous than having no information at all. EGPWS warnings depend on terrain data base and in SV visual picture of the same is provided on a HUD or MFD. EV is a new technology and there is need to discuss requirements and evolve the road map. Choice of sensors for EV requires careful consideration of the band in which the landing lights on the runway operate in addition to other considerations. There is a recent move to replace all runway lights by LEDs which have a different wavelength and the sensors have to be selected with due consideration of these aspects as well as cost. It needs considerable discussion and research to arrive at the right sensor combinations for EV.

Dr PNAP Rao also exhorted the team to consider “life cycle costs” for these sensors. As mentioned by Dr. Kota, automobile sensors may be considered since they would be less costly. Honeywell has a certified EVS on Gulf Stream Business jet but for that system cost was not the criterion at all. We also need to study conditions like fog, smoke etc in India to decide on the right combination of dissimilar sensors like SWIR, MWIR, LWIR, MMW, and visual range video. Multi sensors – image fusion problem has to be studied on the simulator using pilots to fly and evaluate mismatch between SV and EV before flying it on the aircraft. Pilots have to be inducted for evaluations at every step.

Dr. Naveed M Hussain emphasized that the requirements is where we should start. At Boeing, IEVS development started as military requirements for giving SA to the pilots under variety of conditions. Even in the US, most of NAV support is still from ground. For meeting the civil requirements, India would require some of the most advanced technologies in the world. Understanding the dynamic scenarios the pilots are subjected to, the latency effects and dynamic requirements in terms of processing sensor data in real time when several sensors are involved is very important. At Boeing several of these concepts like Highway in the sky, tunnel in the sky etc. started with the military and moved on to civil. Dr. Hussain’s recommendation is to evolve a COTS type of architecture for IEVS such that it could be used like plug and play units. We could start with military requirements, strip the requirements for civil needs with civil performance as the focus and then perhaps we will have the most advanced Civil Vision Systems ever designed. He felt that there is a commercial off the shelf opportunity here and we need to be ambitious. We should “test really” and “test often” and get it up in the real environment. The experience with Boeing has been that ground testing could be successful but many systems could fail in real flight test environments due to power, range, vibration problems etc.

Dr. Kota felt that more than one type of sensor is a necessity and this is an area that needs research. Unnecessary requirements need to be removed and we need to pay attention to this through simulations and arrive at the right set of sensors for the task.

Capt Gurudath felt that instead of having the EVS system on the a/c onboard where it is subjected to vibrations, temp variations etc, it could be located on the ground and the information could be transmitted to the pilot via the high speed links that are available. He expressed that runway lights could be used to define the perimeter of the airfield, and a camera picture of the runway could be transmitted to the pilot in real time. Dr Kota replied that doing this on all airfields in India could have lot more problems than what the single system on the aircraft would. He continued to say that onboard equipments are no longer as expensive as they used to be and this we have learnt on the LCA program where we started with military grade components and today we know that we can replace some of them by COTS components. Even maintenance today is lot less expensive due to Condition Monitoring technology whereby we replace components only if there is a degradation. In the light of these aspects, it is always better to concentrate on a/c and have it land anywhere than have the certification of airfields.

Dr. PNAP Rao mentioned that there is an added bonus of IEVS in that we can see clearly if there are runway incursions by other vehicles or aircraft. We have to look at the system as catering to the total requirement of how to put flight path markers, pathways, HITS and also maybe integrate a weather radar for increased SA for the pilot. With the increasing traffic in today's scenario, the concept is "free flight" also called "performance based navigation". We need concepts to have aircrafts flying closer with their own chosen path without ATCs using perhaps ADS-B. Certification becomes important for this system because it is a little subjective. Certification is not straightforward and we have to use simulators and extensive pilot evaluations for evolving strategies to convince DGCA.

Mrs. Padma Madhuranath commented on requirements needed for drawing up requirements. She thanked Mr. Kamath of Macmet who gave the first support to the workshop by promising a talk on this subject by CAE. The next support came from Honeywell Technologies. She said that important inputs come from pilots and thanked Wg Cdr Rajeev Kothiyal. He had given valuable inputs to Control law development for LCA and can help NAL in coming out with the requirements for ESVS. She thanked the Indian Airlines pilot Capt Gurudath and Dr. Naveed Hussain for their participation. She requested all the panel members with their vast experience to help in drawing up the requirements. Speaking about the need to fix up the sensor specifications, she mentioned that it is a myth that what cannot be fixed in hardware can be fixed up by software. We need to carefully draw up requirements for sensors specifications and use s/w to get some improvements.

Mrs. Padma expressed that the availability of data base of airports for SV to the required resolution of '1m' or less is difficult. Although there are groups of people working in the area, the classified data for the airports is hard to procure. There is a need to identify a group of people who will be responsible for data base generation for Synthetic Vision. Dr. Kota expressed that we could contact DEAL, NRSA and Ananth Technologies from Hyderabad for this purpose.

Dr. Kota summarized the outcome of the panel discussions by mentioning that the total requirements and need is clear. We can only achieve this technology by pooling the expertise from the various organizations. The key to IEVS development would be the civil requirements for this system which could be evolved by stripping down the military requirements. Dr. Kota emphasized that we need to involve persons from DGCA right from the initial stages for evolving strategies for software certification. As to the sensor suite, he said that there are a number of sensors to choose from and we need to come out with an optimum core set which may turn out to be COTS sensors. He also reiterated that sensors and sensor models will have to be obtained as part of AIDE and tested.

The Chairman identified the following members to give their inputs in the areas mentioned for evolving the road-map for IEVS development:

1. Dr. Ronald Kruk, CAE, Canada - Requirement specifications
2. Dr Naveed M Hussain, Boeing, New Delhi – Specification of systems which Boeing has evaluated
3. Dr. Dinesh Ramegowda of HTSL, Bangalore - Certification issues
4. Dr. P.P. Mohanlal, VSSC, Trivandrum - INS/GPS/WAAS/LAAS integration aspects
5. Dr. Girija Gopalratnam, FMCD, NAL - Sensors for IEVS and overall coordination
6. Dr. S.S. Negi of IRDE, Dehradun - IR sensors
7. Gp. Capt. Rajiv Kothiyal,, Deccan Airways and Capt. Gurudath, Indian Airlines - Pilot requirements
8. Dr. Subrata Rakshit, CAIR, Bangalore - Alternate algorithms for image fusion
9. Simulation Group /MSDF Group, FMCD, NAL – Airport details from Airport Authority of India
10. Simulation Group, FMCD, NAL – Aspects of Synthetic vision/Synthetic data base integrity monitoring
11. MSDF Group, FMCD, NAL – Algorithms for Image and Vision fusion/ Integration of INS, GPS, WAAS, LAAS/ Obstacle detection

The Chairman concluded the panel discussions by complementing the excellent arrangements by the MSDF group and thanked the Panel members and the participants for the useful suggestions.

Panel Discussions

Objective: To evolve a Road-map for IEVS Development for RTA through creation of a network of organizations

Integrated Enhanced Vision System (IEVS) for RTA

- **Need for development of technology to provide better operational effectiveness and safety for operation from airports with minimal infrastructure and instrumentation facility under all-weather conditions**
- **IEVS is the proposed technology solution**
- **IEVS enhances situational awareness by providing real time vision to the pilots on an integrated display especially during approach and landing**
- **IEVS can be utilized to address critical areas such as runway incursions; CFIT avoidance; general safety enhancements during approach, landing, and takeoff; and ground operations**
- **Aim is to achieve autonomous Cat III operations through the proper integration of Enhanced Vision System with**
  (i) GPS Landing Systems/Flight Management Systems (GLS/FMS).
  (ii) Other relevant avionics: EGPWS, ADS-B, and TCAS

Some of the Factors to be considered to achieve the required high degree of reliability and redundancy:

- ❑ Type, position and number of sensors – SWIR/LWIR/Video/MMW
- ❑ Required resolution and concurrency of the data base information
- ❑ Content, presentation and location of display information
- ❑ Choice of algorithms for Registration and Fusion to operate in real/near-real time
- ❑ Video-Geo registration
- ❑ Performance of the system during different phases of approach and landing
- ❑ Explore several precision systems using different forms of DGPS enhancements including WAAS, LAAS and GAGAN to support approach and landing

Development steps as envisaged:

- Identify the sensors for EVS
- EVS simulation environment for validation of algorithms
- Images to be fed into a data fusion processor via video i/o interfaces.
- Image fusion algorithm development
- Integration with the full-fledged simulation environment (AIDE)
- Analysis, interpretation and EVS-display generation
- Integration of DGPS/WAAS/LAAS data
- For a given aircraft status vector (position and attitude) and a given set of terrain data several virtual sensor simulations to be carried out
- Validation with flight testing to check for reliability and robustness

Core issues to be addressed:

- ✓ Navigation Data Precision
- ✓ Real time monitoring of Data base integrity and warnings for failures
- ✓ Guidance Symbology and display concepts
- ✓ Separate testing of enabling technologies at each stage of development
- ✓ Final integration to the test aircraft

Workshop

Patrons:

Dr. A.R. Upadhya, Directror, NAL, Bangalore

Dr. Kota Harinarayana, Dr. Raja Ramanna Fellow, NAL, Bangalore

Mrs. Padma Madhuranath, Head, FMCD, NAL, Bangalore

Mr. Shyam Chetty, Joint Head, FMCD, NAL, Bangalore

Coordinators:

Dr. (Mrs) Girija Gopalratnam, FMCD, NAL, Bangalore

Mr. N. Shanthakumar, FMCD, NAL, Bangalore

Members for Panel Discussion:

Dr. Kota Harinarayana, Dr. Raja Ramanna Fellow, NAL, Bangalore

Mrs. Padma Madhuranath, Head, FMCD, NAL, Bangalore

Dr. Ronald V Kruk, Chief Scientist, CAE Inc., CANADA

Dr. Naveed M Hussain, Boeing, New Delhi

Gp. Capt. Rajiv Kothiyal, VP Flight Operations, DECCAN

Dr. PNAP Rao, Honeywell Technologies Solutions Ltd., Bangalore

Capt. Gurudath, Bangalore

Some Important Moments…..

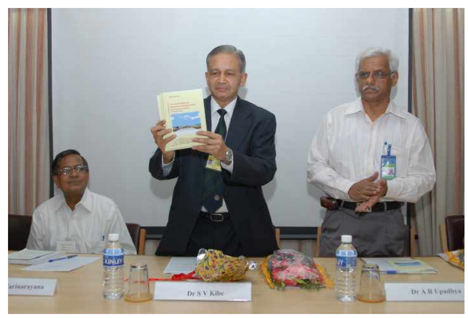

Registeration/8.30am/25 April'08


Welcome address (Dr. A R Upadhya, Director, NAL)/9.00am/25 April'08


Inaugural Address (Dr. Kota Harinarayana, Dr. RajaRamanna Fellow, NAL))/9.30am/25 April'08


Keynote Address (Dr. S V Kibe, Programme Director, SATNAV, ISRO))/10.00am/25 April'08


Mr. N. Shanthakumar (workshop coordinator) Inviting Dr. Kibe for releasing Book of Abstract


Dr. S.V. Kibe releasing Book of Abstract


Mr. Padma Madhuranath, Head, FMCD Inviting speakers


Speaker-Ronald Kruk, Chief Scientist, CAE, Canada

Workshop Participants

Relaxing Moments- High tea

Speaker- Dr. Subrata Rakshit, Sc 'F', CAIR, Bangalore

Lunch Break

Dr. (Mrs) Girija Gopalratnam During Panel Discussion

Panel Discussion Progressing…

Vote of Thanks…

Members Workshop – after receiving special thanks from Head FMCD

National Aerospace Laboratories		***Classification***	Open
		No. of copies	6
Title	Proceedings of two day workshop on Enhanced and Synthetic Vision for Transport Aircraft		
Editors	Girija Gopalratnam, N. Shanthakumar, Sudesh K. Kashyap and VPS Naidu		
Division	FMCD	***NAL Project No***	NWP 00-01-02
Document No.	SP 0811	***Date of issue***	May 2008
Contents	**Pages** 428		
External Participation	-------		
Sponsor	NAL		
Approval	Director, National Aerospace Laboratories		
Remarks	This publication is the outcome of the two day workshop on Enhanced and Synthetic Vision for Transport Aircraft conducted at NAL on 25-26th April 2008		
Keywords	Enhanced Vision, Synthetic Vision, Transport Aircraft, WAAS, LAAS, GAGAN Image Registration, Image Fusion		

Abstract

The regional transport aircraft (RTA-70) proposed to be developed at NAL is expected to have the capability of reliable and safe operation from airports with minimal infrastructure and instrumentation facility under all-weather conditions. Enhanced and Synthetic Vision (ESV) technology aided by satellite navigation has the potential to meet this requirement. A two day workshop on 'Enhanced and Synthetic Vision for Transport Aircraft' was organized by the Multi Sensor Data Fusion group, Flight Mechanics and Control Division with the objective of examining the state of art and identifying gaps in technology/knowledge base in this area and chalk out a plan of action for ESV development at NAL.

This Special Publication gives the abstracts of the presentations at the workshop including the presentation material. It also includes the Summary of the panel discussions which highlights future directions and research needs.